Heathrow Airport Airfield Emission Inventories 2015 to 2020

Report for Heathrow Airport Limited

ED 15940101 | Issue Number 2 | Date 11/10/2023

Customer:

Heathrow Airport Limited

Customer reference:

HAL1000328PO

Confidentiality, copyright & reproduction:

Contact:

Charles Walker
Ricardo Energy & Environment
Bright Building, 1st Floor, Manchester Science Park, Pencroft Way, Manchester, M15 6GZ, United Kingdom

t: +44 (0) 1235 75 3115

e: charles.walker@ricardo.com

Ricardo is certificated to ISO9001, ISO14001 and OHSAS18001

Author:

Charles Walker

Approved By:

Gareth Horton

Date:

11 October 2023

Ricardo Energy & Environment reference:

Ref: ED15940101- Issue Number 2

Table of contents

Glossary

APU Auxiliary Power Unit

ATM Air Transport Movement

BA British Airways

AUWR All Up Weight Return – Heathrow's database that provides information on aircraft engine fits and maximum take-off weights

CAEP Committee on Aviation Environmental Protection

CO_2 Carbon dioxide

EFPS Electronic Flight Processing Strips

GSE Ground Support Equipment

HGV Heavy Goods Vehicle

ICAO International Civil Aviation Organisation

LTO Landing and Take-Off

LGV Light Goods Vehicle

mppa million passengers per annum

NAEI National Atmospheric Emissions Inventory

NATS National Air Traffic Services

NO_x Nitrogen Oxides

NTK Noise and Track-Keeping

nvPM non-volatile Particulate Matter

OPR Overall Pressure Ratio

OSI Operational Safety Instruction

PCA Pre-Conditioned Air

PM Particulate Matter

PM_{10} Inhalable particles with diameters that are generally 10 µm and smaller

$PM_{2.5}$ Inhalable particles with diameters that are generally 2.5 µm and smaller

1 Introduction

This report presents the results of an emission inventory study of Heathrow Airport for the years 2015 to 2020, concentrating on airfield emissions. It is based on the methodology of an inventory and dispersion modelling study for 2013[i] and it surpasses a series of annual updates that were undertaken for 2015[ii], 2016[iii] and 2017[iv]. This report aims to align new inventories for 2019 and 2020 with inventories for 2015 to 2018 that were produced for the Airport Expansion Consultation[v]. The 2015, 2016 and 2017 inventories were compiled as baseline inventories supporting the Heathrow Expansion PEIR[vi] and inventories for 2017 and 2018 were developed further for the anticipated Heathrow Expansion Environmental Statement that was never published.

1.1 Aircraft and APU emissions

Historically, updates to the Heathrow emission inventory were produced annually. They covered aircraft emissions only. The rationale behind the updates was that aircraft were the major contributor to airport emissions and their emissions will change from one year 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, while operational parameters (e.g. taxiing time by aircraft type) are updated on a longer timescale. This concept was applied to generate the historical annual updates. Operational parameters derived from data for 2013 were retained with aircraft movement and fleet mix data updated annually. Additionally, data on taxi and hold times, derived from the electronic flight processing strips (EFPS) and observations of auxiliary power unit (APU) running times reported annually were utilised for the annual updates, as they had become routinely available.

1.1.1 Airport Expansion baseline inventories

The Heathrow Expansion project required inventories that would stand up to the scrutiny of a Public Enquiry. Considering this, baseline inventories were developed for 2015 to 2018 that made best use of all the available data including:

- Updated taxi and hold times, derived from EFPS data (as described above)
- 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 climb and approach profiles
- Inclusion of reduced-engine taxiing in the modelling

This approach has also been applied to the new inventories for 2019 and 2020.

1.1.2 Methodology updates

In addition to the updated operational parameters (paragraph 1.1.1), there have been a number of minor methodology changes from that of the 2013 inventory and dispersion modelling study. These are outlined below. Other details of the methodology for quantifying aircraft emissions were presented in the 2013 report, quoted earlier, and are not discussed further in this report.

As part of the Heathrow Expansion project, the emissions inventories for 2015, 2016 and 2017, previous calculated using the 2013 methodology, were recalculated using the updated methodology. Sections 3.1.1, 3.2.1 and 3.3.1 present comparisons of the results obtained using the two methodologies for NO_x, PM and CO_2, respectively.

Altitude

The ceiling for emissions classed as airport related has been revised from 1,000 m to 3,000 feet. This is to align with the internationally recognised Landing and Take-off Cycle (LTO).

Take-off thrust

For commercial reasons, airlines have become reluctant to share the operational data required to estimate take-off thrusts. Therefore, data from the 2013 study were pooled with the little data that were made available to the Heathrow Expansion project to provide estimates of average take-off thrust separately for twin-engined and four-engined aircraft.

Non-volatile PM emission factors

For the 2013 study and subsequent annual updates non-volatile PM exhaust emission factors were derived from Smoke Numbers taken from the ICAO aircraft engine emissions databank[vii]. The maximum Smoke Number of an engine was subject to CAEP regulatory control although, unlike the situation for NO_x, the standard had not become more stringent over time. Modern jet engines usually have Smoke Numbers well below the CAEP limit, so there was no regulatory pressure for continuous improvement.

In February 2019, the eleventh meeting of the ICAO Committee on Aviation Environmental Protection[viii] (CAEP/11) agreed and approved a new non-volatile Particulate Matter (nvPM) Standard. Separate limits apply to in-production engines manufactured after 1 January 2023 and engines for which an application for a Type Certificate is submitted after 1 January 2023.

Although the standards do not apply to current engines, nvPM emissions factors have been reported for some engines in the ICAO databank since 2020. For the relevant engines these emissions factors have been adopted for the new inventories (2019 and 2020). For other engines, without reported nvPM emissions factors, the Smoke Numbers methodology is retained.

The methodology for the other constituent of PM emissions, volatile PM, has remained unchanged (using the Airport Air Quality Manual[ix] methodology).

Reduced-engine taxiing

Reduced-engine taxiing is the practice of shutting down an engine during taxi operations, which helps reduce fuel use, emissions, and noise. During reduced-engine taxiing it is likely that the APU will need to be kept running so it can provide power to the onboard systems and to start the remaining engines. 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. Considering 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. Primarily for safety reasons, Heathrow have recorded the use of reduced-engine taxiing for departures since the summer of 2014. Currently, they only record if reduced-engine taxiing is used. They do not record the duration of its use or the associated APU use off-stand.

The use of reduced-engine taxiing on arrival is known 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. To address the lack of data on arrival, Heathrow have undertaken a survey of the airlines to understand their procedures for the use of reduced-engine taxi on both arrival and departure.

The 2013 study did not consider the use of reduced-engine taxiing. However, although not included in the main inventories, alternative results were presented in the annual inventory updates that took account of reduced-engine taxiing, albeit making assumptions regarding the duration of its use and the associated APU use off-stand. The Heathrow Expansion project adopted the alternative methodology to include reduced-engine taxiing as a standard component of the inventories. This approach has also been applied to the new inventories for 2019 and 2020.

In the assessment of reduced-engine taxiing we have assumed that aircraft using reduced-engine taxiing will operate on all engines for the final 2-3 minutes of taxi-out; this is to allow for the engines to fully warm-up prior to take-off.

Although reduced-engine taxiing is not recorded for arrivals, the airline survey allows us to extend the methodology to taxi-in. Of the airlines that responded to the survey, all of those who used reduced-engine taxiing on departure also used it on arrival. Additionally, some airlines that did not use reduced-engine taxiing on departure did use it on arrival. We have therefore assumed that reduced-engine taxi-in is used whenever taxi-out is recorded as being used on the corresponding departure of the turnaround and, more generally, we have assumed that reduced-engine taxi-in is used for all arrivals where airlines responded positively its use.

Conservatively, we have assumed that aircraft using reduced-engine taxiing will operate on all engines for the first 2-3 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.

During reduced-engine taxiing we have assigned the standard ICAO thrust setting of 7%. For taxi-out and for taxi-in on all engines, the PSDH recommended that idle thrust settings lower than 7% should be used. However, these lower thrust setting were not considered to be appropriate for reduced-engine taxiing. For conventional taxiing, the PSDH thrust recommendations have been retained in the methodology.

We have also assumed that airlines will operate their APUs whilst taxiing using reduced engines as it is likely that the APU would be needed to provide on-board power to the aircraft and to start the remaining engine(s).

1.2 GSE emissions

In line with the Heathrow Expansion project inventories this assessment encompasses all airfield sources including ground support equipment (GSE).

Emissions from GSE are estimated from the quantities of fuel dispensed airside. It is recognised that if any fuel is sourced landside and brought in airside it will be missed in the inventory. Likewise, any fuel sourced airside and used landside will be double counted. However, these represent a very small fraction of the total airside fuel and will to some extent cancel out.

For the purpose of emission calculation, the fuel is distributed amongst the vehicles and equipment that are registered to operate airside, as obtained from the annual airside pass database. The fuel distribution is weighted according to the operator’s fuel purchases and the vehicle engine size.

Emission factors for road vehicles, which vary with fuel type, speed and vehicle type (e.g. car, LGV, HGV) and emission standard, were taken from COPERT v5[x]. Emission factors for non-road mobile machinery were taken from the EMEP/EEA air pollutant emission inventory guidebook 2019[xi].

1.3 Stationary sources

In line with the Heathrow Expansion project inventories this assessment includes emissions from heating plant and the fire training ground.

Emissions from these stationary sources were estimated from annual fuel use data, supplied by Heathrow Airport using emission factors either from the NAEI or, where available, derived from airport stack monitoring data.

1.4 Surface access

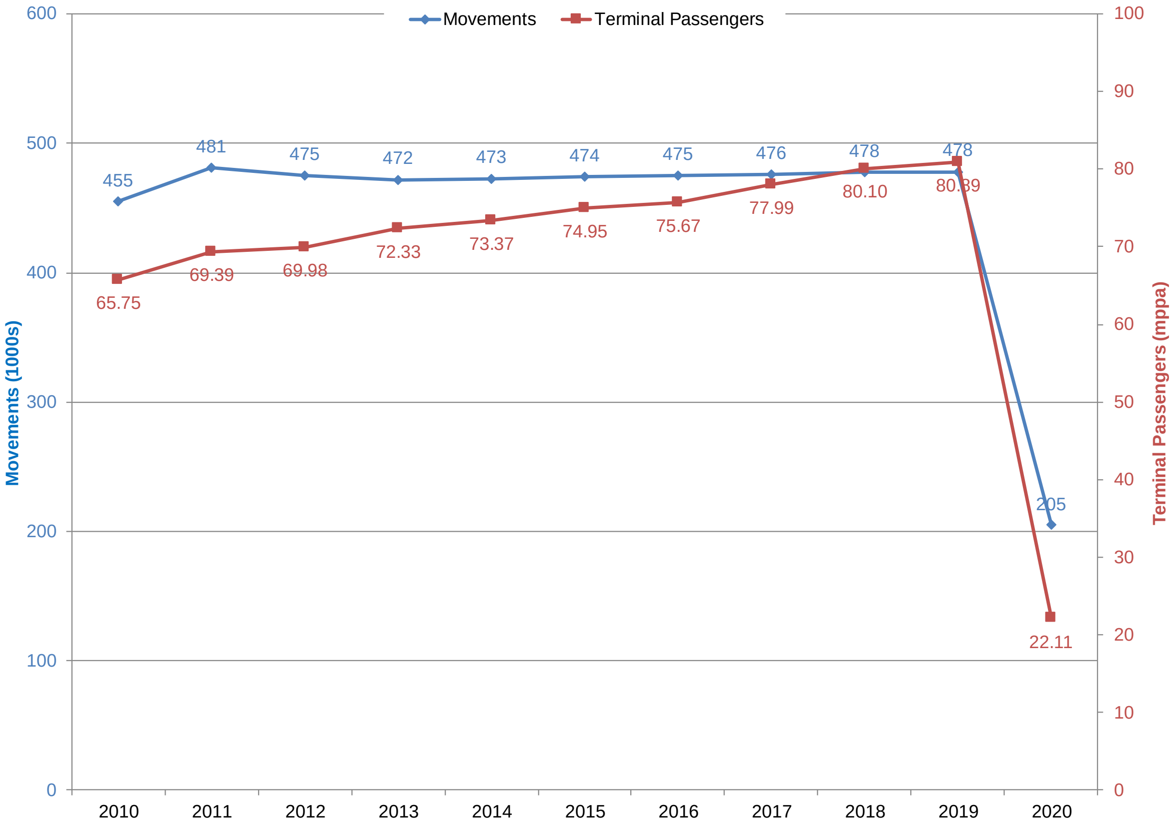
The Heathrow Expansion project also assessed emissions from surface access including the airport car parks and landside road network. However, these sources are beyond the scope of this study.

2 Input data

2.1 Movements and passenger numbers

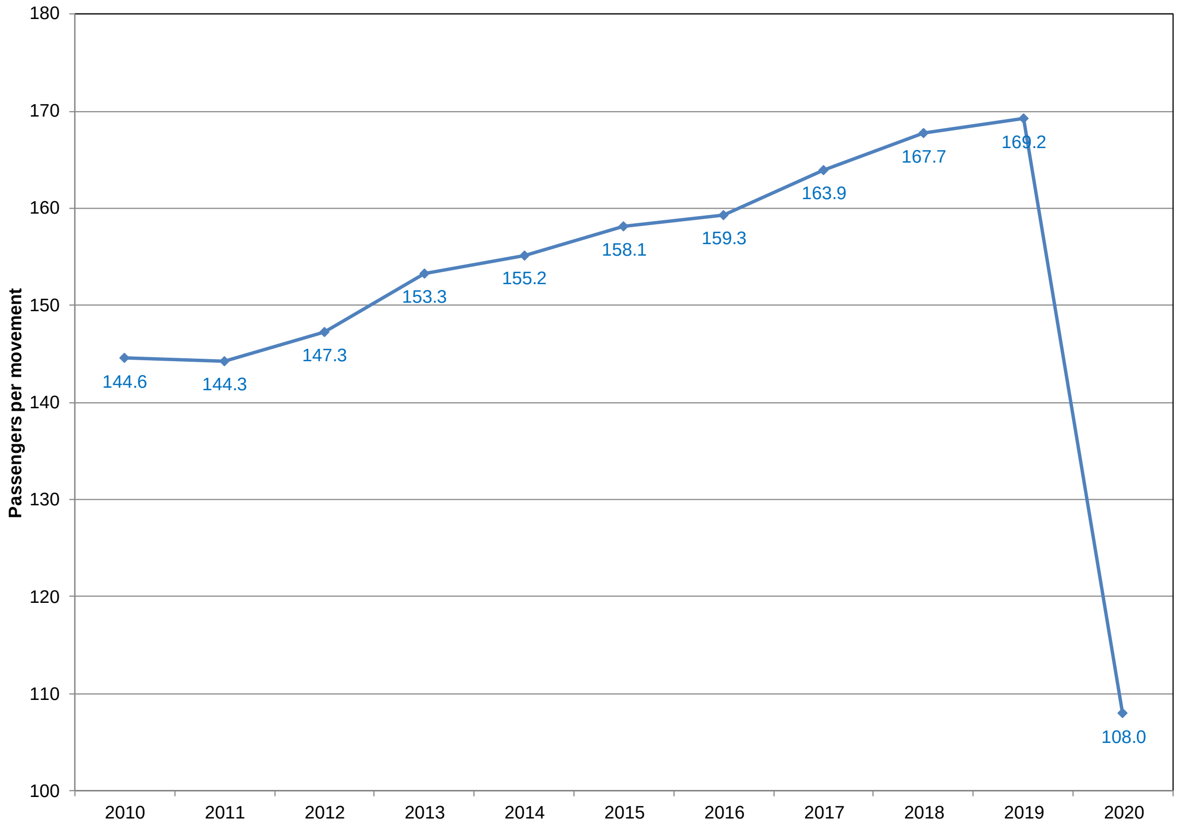
Figure 1 shows the trend in the number of aircraft movements and passengers over the last ten years. Up until 2019, the number of aircraft movements has remained broadly constant, reflecting the fact that the airport is operating close to maximum capacity. However, the number of passengers has risen steadily over the same period, accommodated by a larger number of passengers per movement on average (Figure 2). In 2020 there was a dramatic downturn in both movements and passengers due to the COVID-19 pandemic. Figure 2 also shows a dramatic downturn in passengers per movement in 2020, reflecting the reduced passenger load factors seen during the pandemic.

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 were provided by Heathrow Airport as an extract from their Power BI/HDS information. For each aircraft movement the following data fields are used in the emission inventory calculations:

- 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 or departure
- stand number

The last two items are used to determine taxiing and other times-in-mode.

The inventory includes emissions from both Air Transport Movements (ATMs) and non-ATMs (for example, positioning movements and private flights).

Table 1 gives a breakdown of the movements by aircraft type for each year 2015 to 2020. The average annual increase in movements seen between 2015 and 2019 was about 0.2% whereas the average growth in passenger numbers over the same period was 1.9%.

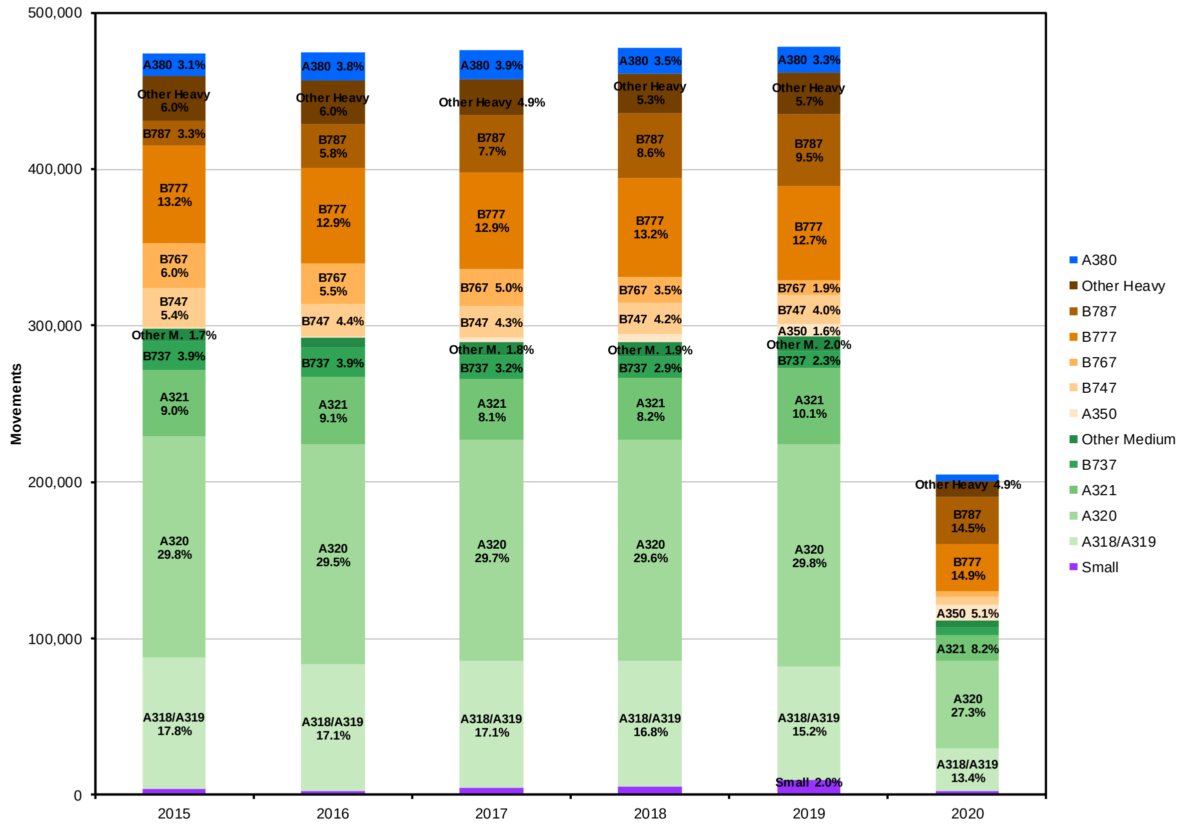
Table 1 Aircraft movements[1] by aircraft type: 2015 to 2020

Aircraft Type	2015	2016	2017	2018	2019	2020
Small	3,586	2,504	4,268	5,189	9,407	2,387
Medium	294,843	289,774	284,982	284,151	283,738	108,913
A318/A319	84,352	81,196	81,371	80,179	72,503	27,334
A320	141,169	140,303	141,347	141,556	142,594	55,842
A321	42,765	43,040	38,541	39,283	48,171	16,721
B737	18,376	18,712	15,174	14,003	10,758	4,836
Others	8,181	6,523	8,549	9,130	9,712	4,180
Heavy	160,869	164,435	168,182	171,739	168,919	88,951
A350	58	714	2,809	5,037	7,571	10,503
B747	25,662	20,668	20,564	20,277	18,893	4,473
B767	28,342	25,949	23,749	16,575	9,191	3,583
B777	62,611	61,241	61,306	63,234	60,611	30,521
B787	15,601	27,591	36,484	41,266	45,423	29,772
Other	28,595	28,272	23,270	25,350	27,230	10,099
A380	14,826	18,265	18,483	16,696	15,996	4,481
Total	**474,124**	**474,978**	**475,915**	**477,775**	**478,060**	**204,732**

[1] ATMs and non-ATMs

Figure 3 shows the trend in the number of aircraft movements broken down by aircraft type. There have been some significant changes to the fleet mix between 2015 and 2020. The Boeing 787 (B787) has increased its share from 3.3% of the movements in 2015 to 14.5% of the movements in 2020. Also, the A350 entered the fleet in 2016 and in 2020 had a 5.1% share of the movements. These increases appear to have been partially at the expense of the Boeing 767 (B767), whose share has reduced from 6.0% in 2015 to 1.8% in 2020 and the Boeing 747 (B747), whose share has reduced from 5.4% in 2015 to 2.2% in 2020. However, there has been a general shift from medium sized aircraft to heavies[1]. In 2015 medium sized aircraft represented 62.2% of the fleet and heavies (excluding the A380) represented 33.9%. By 2020 the medium share had reduced to 53.2% and heavies (excluding the A380) had increased to 43.4%. It should be acknowledged that movement numbers in 2020 were heavily affected by the COVID-19 pandemic. However much of the changes to the fleet were also evident in 2019. The shift towards a heavier fleet can be seen in the data to 2019 that are presented in Figure 2 (average passengers per movement). The 2020 data in Figure 2 are affected by reduced passenger load factors to such an extent that the shift towards a heavier fleet is concealed.

Figure 3 Number of movements[1] by aircraft type: 2015 to 2020



[1] ATMs and non-ATMs

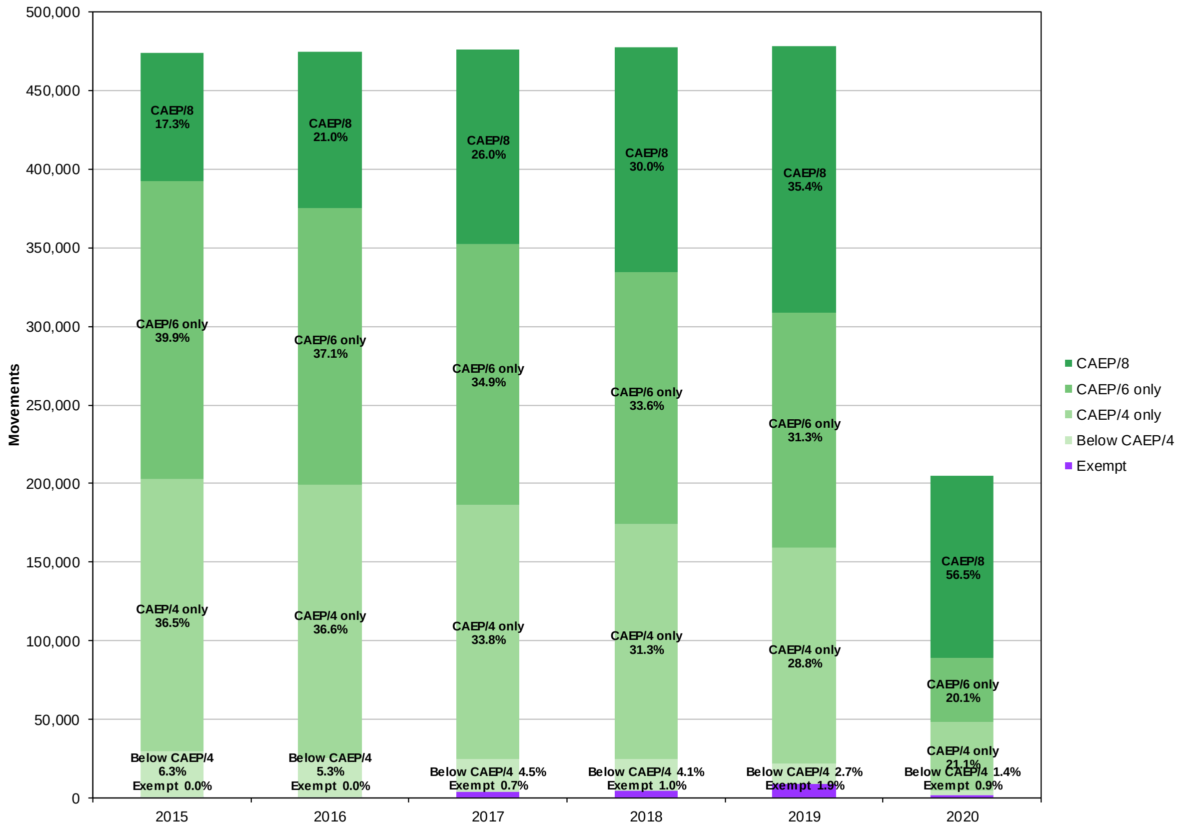
---

[1] In essence, medium-sized aircraft are single-aisle airliners, excluding regional jets and turboprops, while heavies are twin-aisle airliners. The most common types under each category are shown in Table 1

2.3 Engine assignment

Aircraft engine assignments have been taken directly from the airlines via Heathrow's AUWR database. Figure 4 shows the trend in the number of movements by aircraft meeting the various CAEP emission standards.

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. Jet engines below 26.7 kN (6,000 lb) thrust and turboprops are exempt from the CAEP regulations.

Up until 2019, 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 only 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 jet engines[2] since 1st January 2013 must comply with the CAEP/6 standard, while all new jet engines[2] types since 1st January 2014 must comply with the CAEP/8 standard). Between 2016 and 2019 there is also a noticeable increasing number of exempt aircraft. This reflects growth in the number of turboprop aircraft, which are not covered under the CAEP regulations.

[2] Rated 26.7 kN (6,000 lb) thrust and above

2.4 Taxi and hold times

The taxi and hold times for are taken from data 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[3].

Therefore, in addition to taxi-out time, it also includes times for hold, line-up and pilot reaction, which have 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 the vast majority of departures with an EFPS record so that they had individual taxi-out and hold times, and similarly for arrivals. For the other movements that could not be matched, times were taken from tables of times by runway/apron combination derived by averaging the EFPS data.

Table 2 shows taxi-in times derived from data for the years 2015 to 2020, by runway and terminal. Table 3 and Table 4 show similar data for taxi-out and hold respectively.

Table 2 Aircraft taxi-in times: 2015 to 2020

Runway	Terminal	Taxi-in (s)					
		2015	2016	2017	2018	2019	2020
09L	T1[a]	256	300	N/A	N/A	N/A	N/A
09L	T2	449	421	449	474	476	431
09L	T3	426	438	469	504	494	449
09L	T4	732	707	718	741	737	550
09L	T5	495	473	463	533	502	453
09L	Cargo	709	684	681	757	764	584

[3] 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.

Runway	Terminal	Taxi-in (s)					
		2015	2016	2017	2018	2019	2020
09R	T1[a]	452	489	N/A	N/A	N/A	N/A
09R	T2	332	334	328	363	346	340
09R	T3	442	450	490	472	472	429
09R	T4	297	292	296	296	284	314
09R	T5	603	599	656	630	598	520
09R	Cargo	340	288	308	336	292	373
27L	T1[a]	513	581	3062	N/A	N/A	N/A
27L	T2	382	355	378	421	406	412
27L	T3	340	368	387	430	447	428
27L	T4	375	362	362	376	367	361
27L	T5	438	461	447	475	475	438
27L	Cargo	219	200	219	225	215	271
27R	T1[a]	290	366	517	N/A	N/A	N/A
27R	T2	531	508	526	546	544	499
27R	T3	382	403	411	443	446	422
27R	T4	745	774	748	740	743	718
27R	T5	414	434	410	447	442	400
27R	Cargo	677	653	644	667	669	605

[a] Terminal 1 was closed during 2015. However, there were a few movements from remote stands associated with T1 during 2016 and 2017.

Table 3 Aircraft taxi-out times: 2015 to 2020

Runway	Terminal	Taxi-out (s)					
		2015	2016	2017	2018	2019	2020
09L	T1[a]	518	N/A	N/A	N/A	N/A	N/A
09L	T2	845	734	794	705	855	717
09L	T3	712	747	652	759	794	604
09L	T4	935	723	886	661	831	732
09L	T5	637	607	641	860	622	516
09L	Cargo	763	606	612	816	679	802
09R	T1[a]	803	913	1031	N/A	N/A	N/A
09R	T2	604	638	672	635	630	639
09R	T3	609	642	653	663	651	629
09R	T4	596	614	610	603	592	566
09R	T5	530	527	518	617	579	532
09R	Cargo	541	536	558	565	532	508
27L	T1[a]	577	629	762	N/A	N/A	N/A
27L	T2	463	458	459	475	482	485
27L	T3	661	676	677	687	699	687
27L	T4	544	556	528	524	516	496
27L	T5	815	832	821	868	881	796
27L	Cargo	656	703	681	688	673	612

Runway	Terminal	Taxi-out (s)					
		2015	2016	2017	2018	2019	2020
27R	T1[a]	519	554	600	N/A	N/A	N/A
27R	T2	568	563	561	590	594	559
27R	T3	747	726	726	760	754	711
27R	T4	513	504	496	499	496	512
27R	T5	852	779	779	880	849	726
27R	Cargo	678	644	696	685	691	736

[a] Terminal 1 was closed during 2015. However, there were a few movements from remote stands associated with T1 during 2016 and 2017.

Table 4 Aircraft hold[1] times: 2015 to 2020

Runway	Terminal	Hold (s)					
		2015	2016	2017	2018	2019	2020
09L	T1[a]	107	N/A	N/A	N/A	N/A	N/A
09L	T2	587	418	468	511	635	347
09L	T3	547	355	446	559	642	332
09L	T4	806	753	755	712	1153	336
09L	T5	671	419	548	728	599	377
09L	Cargo	673	1013	629	547	799	330
09R	T1[a]	628	663	603	N/A	N/A	N/A
09R	T2	638	661	648	662	686	344
09R	T3	694	711	698	697	705	413
09R	T4	673	700	701	709	729	451
09R	T5	687	711	710	704	709	397
09R	Cargo	519	505	537	580	582	288

Runway	Terminal	Hold (s)					
		2015	2016	2017	2018	2019	2020
27L	T1[a]	593	653	747	N/A	N/A	N/A
27L	T2	552	592	604	575	594	382
27L	T3	620	652	660	622	637	493
27L	T4	551	575	601	601	617	486
27L	T5	590	617	632	597	620	434
27L	Cargo	551	505	515	519	544	351
27R	T1[a]	536	585	378	N/A	N/A	N/A
27R	T2	534	586	572	538	558	393
27R	T3	578	629	625	583	598	515
27R	T4	826	879	873	862	890	760
27R	T5	558	618	623	576	599	457
27R	Cargo	747	756	777	782	813	451

[1] Includes time for line-up and pilot reaction.
[a] Terminal 1 was closed during 2015. However, there were a few movements from remote stands associated with T1 during 2016 and 2017.

Table 5 shows average taxi and hold times weighted over all movements for the years 2015 to 2020. Generally, there is only modest year-on-year variation in taxi and hold times. However, the variation is more apparent for individual runway and terminal pairings. For 2020, there is a significant reduction in hold times, due to the lower movement numbers seen during the COVID-19 pandemic.

Table 5 Weighted average taxi and hold[1] times

Mode	2015	2016	2017	2018	2019	2020
Taxi-In	451	453	447	491	480	440
Taxi-Out	661	655	662	688	688	646
Hold	609	648	643	631	640	433

[1] Includes time for line-up and pilot reaction.

2.5 APU running times

The APU running times are derived from observations of APU running times reported annually. The APU data were supplied by Heathrow Airport in the same form as they were provided for previous inventories. 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, as reduced-engine taxiing is now a standard component of the methodology, APU use off-stand is also accounted for.

Table 6 shows the APU on-stand running times derived from data for the years 2015 to 2020. APU use off-stand is not shown is the table as it is not recorded. It is, however, estimated from reduced engine taxi and EFPS data.

On-stand running times for narrow-bodied aircraft are broadly similar for all years. However, for wide-bodied aircraft (excluding the A380) there is more year-on-year variability. On-stand running times peaked in 2017, most likely as a result of issues with pre-conditioned air (PCA) use, which first became apparent in 2016.

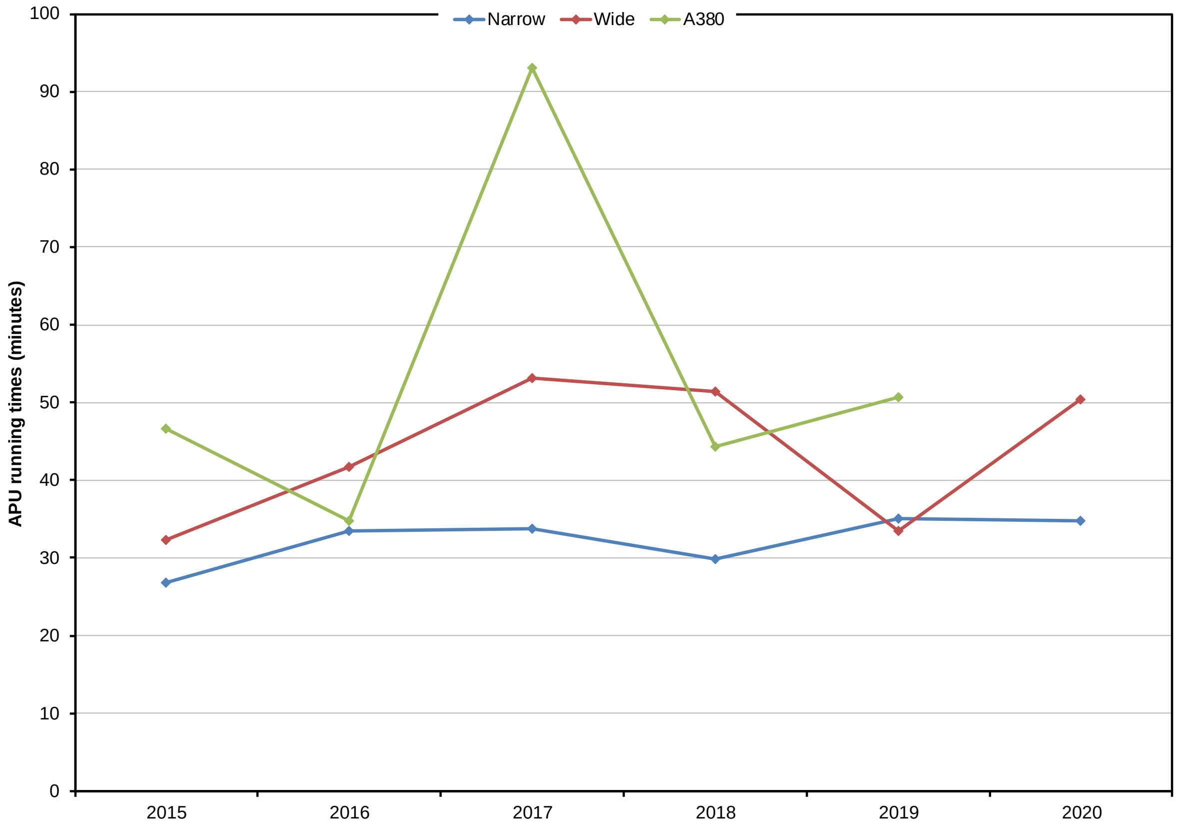
The large year-on-year variability seen for the A380 is likely to be an artefact of the smaller sample sizes involved. In 2020, there were no observations made of A380 departures, so a 5-year average time was assumed.

Figure 5 shows the trend in the APU on-stand running times since 2015.

Table 6 APU on-stand running times: 2015 to 2020

		APU running time (minutes)					
		2015	2016	2017	2018	2019	2020
Narrow-bodied	Arrival	6.9	9.9	9.2	9.3	10.9	12.0
	Departure	19.9	23.6	24.6	20.6	24.2	22.7
	Total	26.8	33.5	33.8	29.9	35.1	34.7
Wide-bodied	Arrival	8.2	11.2	10.6	11.6	14.9	14.1
	Departure	24.0	30.6	42.6	39.7	18.5	36.3
	Total	32.3	41.8	53.1	51.3	33.4	50.4
A380	Arrival	11.2	16.1	27.1	11.9	18.9	15.8
	Departure	35.5	18.7	66.0	32.4	31.8	N/A
	Total	46.7	34.7	93.1	44.3	50.7	N/A

Figure 5 APU running times



2.6 Other times in mode

Runway occupancy times are taken form Heathrow's ground radar system OPAS.

For each movement, OPAS records the aircraft position at 1 second intervals. These have been analysed to provide average take-off roll time by aircraft type and runway block[4] and landing roll times by aircraft type and runway exit block for each year.

For take-off roll, the analysis accounts for time spent at the runway head prior to departure, with the aim of estimating the time spent at high thrust during the take-off roll. Likewise, any rolling take-offs, where the aircraft does not stop on the runway prior to take-off but continues by opening the throttle either during the turn on the runway or immediately after rolling out, are accounted for.

Times in approach, initial climb and climb-out are taken from Heathrow's noise and track keeping system (NTK). These have been analysed to provide average approach, initial climb and climb-out times by aircraft type for each year.

[4] Runway block is required to account for intersection take-offs.

Table 7 shows approach times derived from data for the years 2015 to 2020 and Table 8 and Table 9 show the initial-climb and climb-out times, respectively.

Table 7 Approach times: 2015 to 2020

	Phase 1[a] (s)						Phase 2[b] (s)					
	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020
A318	92.4	77.3	83.8	87.1	79.5	n/a	130.8	160.3	168.1	183.8	162.2	n/a
A319	70.5	70.2	72.8	69.7	71.3	71.5	129.8	160.9	167.5	161.6	164.6	166.7
A320	70.5	69.8	73.5	69.7	70.8	71.8	126.6	156.6	163.0	158.1	159.6	160.4
A320 neo	n/a	n/a	n/a	n/a	70.6	71.7	n/a	n/a	n/a	n/a	162.6	162.9
A321	71.4	70.5	72.4	70.7	71.7	78.0	129.2	153.4	157.6	155.1	155.6	152.7
A321 neo	n/a	n/a	n/a	n/a	71.4	75.0	n/a	n/a	n/a	n/a	159.1	167.8
A350-900	n/a	79.4	80.0	80.4	75.5	83.4	n/a	156.9	165.4	154.0	156.9	161.0
A350-1000	n/a	n/a	n/a	81.2	79.8	75.4	n/a	n/a	n/a	151.9	154.9	158.9
B747-400	69.7	68.8	71.0	68.5	69.4	77.0	117.0	150.4	151.9	150.5	153.2	144.8
B777-200	70.8	68.8	71.6	67.1	68.3	71.1	127.7	151.5	158.2	151.6	155.7	156.8
B777-200LR	78.8	71.7	70.5	84.8	72.9	74.7	139.4	150.0	155.4	149.8	155.1	155.8
B777-300ER	72.9	73.9	75.7	73.1	71.8	75.8	125.8	148.3	151.9	151.2	154.2	155.9
B787-8	72.4	71.7	74.5	73.1	71.6	74.7	138.0	152.7	156.4	150.9	154.5	159.1
B787-9	69.3	69.2	71.4	68.9	69.8	71.5	130.5	148.7	155.4	147.4	153.4	152.5
B787-10	n/a	n/a	n/a	n/a	70.4	68.6	n/a	n/a	n/a	n/a	153.8	148.1
A380-800	74.3	73.6	74.9	71.6	72.5	75.4	131.4	159.7	162.9	156.7	160.9	162.1

[a] from 3,000 feet to 2,000 feet altitude.
[b] from 2,000 feet altitude to threshold.

Table 8 Initial-climb times[1]: 2015 to 2020

	To 1,000 feet (s)						To 1,500 feet (s)					
	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020
A318	22.0	20.9	20.3	21.2	20.8	n/a	34.0	32.9	33.4	34.3	32.3	n/a
A319	23.9	22.2	21.6	22.0	21.5	22.2	39.0	37.6	36.2	37.3	35.8	36.1
A320	21.4	19.4	18.9	19.2	18.7	19.4	36.1	33.8	32.6	33.4	32.0	31.6
A320 neo	n/a	n/a	n/a	n/a	19.2	19.9	n/a	n/a	n/a	n/a	33.6	33.5
A321	21.0	18.8	18.0	18.4	18.4	21.6	34.0	31.2	29.6	30.7	30.3	34.2
A321 neo	n/a	n/a	n/a	n/a	19.7	20.6	n/a	n/a	n/a	n/a	34.3	34.2
A350-900	n/a	18.3	18.5	18.6	18.4	19.0	n/a	35.2	32.7	34.2	33.5	31.7
A350-1000	n/a	n/a	n/a	n/a	17.5	18.4	n/a	n/a	n/a	n/a	31.9	32.0
B747-400	35.3	34.4	33.8	35.1	34.8	n/a	56.3	56.2	54.8	57.5	56.8	n/a
B777-200	23.9	22.9	21.2	21.8	21.7	22.3	37.9	37.9	35.2	36.2	35.4	36.3
B777-200LR	21.1	20.9	17.5	20.0	18.7	n/a	32.3	33.3	27.8	32.0	30.7	n/a
B777-300ER	22.6	20.5	19.5	20.1	19.6	21.9	33.8	32.0	30.7	31.8	30.9	33.7
B787-8	28.8	25.8	23.8	23.7	23.5	25.6	42.4	40.1	37.2	37.7	36.6	38.7
B787-9	27.1	26.9	26.5	24.3	23.6	25.9	41.5	41.2	40.5	38.3	36.4	39.6
B787-10	n/a	n/a	n/a	n/a	23.6	23.8	n/a	n/a	n/a	n/a	36.5	36.3
A380-800	42.9	40.0	39.0	40.9	38.9	41.3	72.0	68.9	62.9	64.2	62.8	62.9

[1] Times for cutback at 1,000 feet and 1,500 feet are given for aircraft types where either is used depending on operator.

Table 9 Climb-out times: 2015 to 2020

	From 1,000 feet (s)						From 1,500 feet (s)					
	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020
A318	72.1	73.2	72.3	73.9	67.5	n/a	60.1	61.3	59.2	60.8	55.9	n/a
A319	69.4	69.1	67.9	69.1	67.2	65.0	54.3	53.7	53.3	53.9	52.9	51.1
A320	77.0	75.6	74.5	76.7	74.5	68.7	62.3	61.2	60.8	62.4	61.2	56.4
A320 neo	n/a	n/a	n/a	n/a	63.5	60.7	n/a	n/a	n/a	n/a	49.1	47.1
A321	74.2	73.1	70.4	74.0	73.5	68.7	61.3	60.7	58.8	61.8	61.6	56.1
A321 neo	n/a	n/a	n/a	n/a	64.1	62.8	n/a	n/a	n/a	n/a	49.6	49.2
A350-900	n/a	71.6	68.7	76.3	70.0	62.4	n/a	54.7	54.5	60.7	54.9	49.7
A350-1000	n/a	n/a	n/a	n/a	66.6	72.9	n/a	n/a	n/a	n/a	52.2	59.3
B747-400	69.2	66.0	64.0	65.7	65.0	n/a	48.2	44.1	43.0	43.3	43.1	n/a
B777-200	80.0	81.1	76.8	80.9	78.7	87.4	66.0	66.1	62.9	66.6	65.0	73.3
B777-200LR	54.0	56.1	47.8	53.5	54.5	n/a	42.8	43.8	37.5	41.5	42.4	n/a
B777-300ER	63.9	63.7	62.3	61.9	61.3	57.7	52.6	52.2	51.1	50.1	49.9	45.9
B787-8	64.4	65.2	61.5	61.7	67.2	68.7	50.7	50.9	48.1	47.8	54.1	55.6
B787-9	76.4	75.6	72.4	72.5	71.6	70.8	62.1	61.4	58.5	58.6	58.8	57.1
B787-10	n/a	n/a	n/a	n/a	70.0	57.8	n/a	n/a	n/a	n/a	57.1	45.3
A380-800	91.3	90.0	92.0	96.0	91.8	72.7	62.2	61.1	68.1	72.6	68.0	51.1

[1] Times for cutback at 1,000 feet and 1,500 feet are given for aircraft types where either is used depending on operator.

2.7 Take-off thrust

For commercial reasons, airlines have become reluctant to share the operational data required to estimate take-off thrusts. Therefore, data from the 2013 study were pooled with the little data that were made available to the Heathrow Expansion project to provide estimates of average take-off thrust separately for twin-engined and four-engined aircraft.

The assumptions used for the inventories produced for the anticipated Heathrow Expansion Environmental Statement are shown in Table 10.

Table 10 Take-off thrusts

Aircraft type	Reduced thrust setting (%)	Flights using 100% thrust (%)
Narrow-body, twin-engined	80 6	6
Wide-body, twin-engined	80 6	6
Wide-body, four-engined	84 14	14

2.8 Reduced engine taxiing

Table 11 shows the percentage arrivals and departures using reduced engine taxiing for the years 2015 to 2020. There is a clear decline in reduced engine taxiing on departure. The reasons for this are unclear, but possible explanations are that for modern jets the practice is less beneficial. The Boeing 787 is incapable of using reduced engine taxiing due to its APU capabilities. There are also issues relating to warm up times on some A320 neo engines. These factors may be more widespread and affect other modern jets. It may also be possible that airlines have not found that the fuel savings outweigh the safety concerns of starting an engine during taxi-out.

For taxi-in, reduced engine taxi use is estimated from data from a survey that was undertaken for the 2017 update. Reduced engine taxiing has remained relatively constant. However, this may be an artefact of the survey that was done to establish its prevalence, and the fact that the survey has not been recently updated.

Table 11 Reduced engine taxi use: 2015 to 2020

	2015	2016	2017	2018	2019	2020
Arrivals	80%	77%	78%	77%	78%	76%
Departures	21%	17%	18%	13%	11%	6%

3 Results

3.1 NO_x

Table 12 shows airfield NO_x emissions broken down by source category. For aircraft emissions these sources are the phases of the LTO cycle as reported in the 2013 inventory and dispersion modelling study and the subsequent annual updates.

Aircraft NO_x emissions increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 5% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer low-NO_x aircraft types into the fleet, particularly the A320 neo and A321 neo. There is also some year-on-year variation due to meteorological effects and variations in operational data, such as APU running times and taxiing times, that influence emissions.

GSE emissions have fallen year-on-year since 2015. This is due to the ground fleet turnover, with older equipment being retired and replaced with either newer equipment with tighter emissions standards or with electric equipment.

NO_x emissions from stationary sources have increased year-on-year since 2017, due to increased use of biomass as a fuel. The savings achieved in net CO_2 emissions from biomass burning apparently come at a cost of increased NO_x emissions.

NO_x emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

Table 12 Breakdown of airfield NO_x emissions by source category: 2015 to 2020

Source Category	Annual NO_x emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Aircraft						
Ground-level						
Landing roll	48.67	61.85	68.85	40.20	39.28	19.01
Taxi-in	136.78	138.30	137.62	150.74	143.80	59.23
Taxi-out	245.44	243.67	246.21	259.81	253.33	104.45
Hold	231.03	246.00	243.74	242.47	239.14	69.92
Take-off roll	761.82	776.15	798.02	1017.97	970.91	435.82
APU	253.39	314.13	332.49	299.29	257.59	135.01
Engine testing[1]	2.80	2.80	2.80	2.80	2.80	2.80
Total ground-level	**1679.94**	**1782.89**	**1829.73**	**2013.29**	**1906.85**	**826.23**
Elevated						
Approach	503.45	591.20	619.62	611.20	605.09	272.94
Initial climb	719.60	670.83	663.13	688.11	638.01	273.80
Climb out	1418.53	1442.37	1522.38	1607.21	1507.57	644.91
Total elevated	**2641.58**	**2704.39**	**2805.14**	**2906.53**	**2750.68**	**1191.64**
Total aircraft	**4321.52**	**4487.28**	**4634.87**	**4919.82**	**4657.52**	**2017.87**
GSE[2]	**156.03**	**143.73**	**127.82**	**122.00**	**95.07**	**52.39**

Source Category	Annual NO_x emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Stationary sources[3]						
Gas	N/A	N/A	N/A	N/A	19.31	15.32
Gas-oil	N/A	N/A	N/A	N/A	10.45	8.37
LPG	N/A	N/A	N/A	N/A	0.04	0.00
Biomass	N/A	N/A	N/A	N/A	35.12	42.42
(BA gas)	N/A	N/A	N/A	N/A	34.14	34.14
Total stationary	**74.92**	**55.64**	**50.64**	**76.54**	**99.06**	**100.24**
Total airfield	**4552.48**	**4686.65**	**4813.33**	**5118.36**	**4851.65**	**2170.50**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018.

Table 13 shows the values of annual aircraft LTO NO_x emissions normalised by the number of passengers and movements. The NO_x per passenger is highest in 2020. However, this year is heavily affected by reduced passenger load factors as a result of the COVID-19 pandemic. Prior to 2020, the NO_x per movement increased year-on-year between 2015 and 2018 in line with the shift towards larger aircraft. However, this trend did not continue into 2019, mainly due to the propagating of newer cleaner aircraft types into the fleet

Table 13 LTO NO_x emissions per passenger and per movement: 2015 to 2020

	2015	2016	2017	2018	2019	2020
LTO NO_x (tonnes per year)	4321.52	4487.28	4634.87	4919.82	4657.52	2017.87
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11
LTO NO_x (g per passenger[1])	57.66	59.30	59.43	61.42	57.58	91.27
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73
LTO NO_x (kg per movement[2])	9.12	9.45	9.74	10.30	9.74	9.86

[1] Excludes transit passengers
[2] ATMs and non-ATMs

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) peaked in 2018 at the point where increasing emissions due to higher passenger number had not been sufficiently offset by the propagation of newer cleaner aircraft types in into the fleet (refer to Table 12).

Table 14 gives a breakdown of ground-level aircraft NO_x emissions (omitting APUs and engine testing) by aircraft type. The larger aircraft types (heavy and A380) together contribute approximately three quarters of the emissions in each period (four fifths in 2020), despite accounting for less than half of the total movements. Conversely, the A320 aircraft family (A318/A319, A320 and A321) only account for between a fifth and a quarter of the emissions in all years except 2020, despite accounting for more than half of the total movements. In 2020, they accounted for only a sixth of the emissions from just under half the movements.

Table 14 also gives ground-level emissions per movement (excluding APU and engine testing emissions) for each aircraft type. 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 emissions 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 14 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type: 2015 to 2020

(a)

	NO_x emissions (tonnes/year)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	2.47	1.71	1.47	1.79	2.78	0.71
Medium	382.44	379.27	371.62	397.22	391.76	130.22
A318/A319	97.55	97.31	93.86	99.83	92.42	31.23
A320	176.20	175.08	178.76	186.64	181.18	61.63
A321	73.48	74.66	69.24	79.26	91.43	27.05
B737	21.85	21.95	17.81	18.39	14.27	5.62
Others	13.36	10.28	11.96	13.09	12.46	4.69
Heavy	897.20	909.59	946.32	1121.64	1071.90	510.95
A350	0.32	3.43	11.30	25.74	40.02	59.79
B747	185.74	151.92	160.11	187.61	175.04	36.02
B767	87.37	76.68	81.91	66.05	30.78	11.06
B777	412.84	399.47	400.17	497.55	455.61	215.05
B787	74.33	146.37	183.49	205.49	227.31	145.72
Other	136.59	131.71	109.33	139.21	143.13	43.31
A380	141.64	175.38	175.02	190.55	180.01	46.55
Total	**1423.75**	**1465.96**	**1494.44**	**1711.20**	**1646.45**	**688.42**

(b)

	NO_x emissions (%)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.2	0.1	0.1	0.1	0.2	0.1
Medium	26.9	25.9	24.9	23.2	23.8	18.9
A318/A319	6.9	6.6	6.3	5.8	5.6	4.5
A320	12.4	11.9	12.0	10.9	11.0	9.0
A321	5.2	5.1	4.6	4.6	5.6	3.9
B737	1.5	1.5	1.2	1.1	0.9	0.8
Others	0.9	0.7	0.8	0.8	0.8	0.7
Heavy	63.0	62.0	63.3	65.5	65.1	74.2
A350	0.0	0.2	0.8	1.5	2.4	8.7
B747	13.0	10.4	10.7	11.0	10.6	5.2
B767	6.1	5.2	5.5	3.9	1.9	1.6
B777	29.0	27.2	26.8	29.1	27.7	31.2
B787	5.2	10.0	12.3	12.0	13.8	21.2
Other	9.6	9.0	7.3	8.1	8.7	6.3
A380	9.9	12.0	11.7	11.1	10.9	6.8
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

(c)

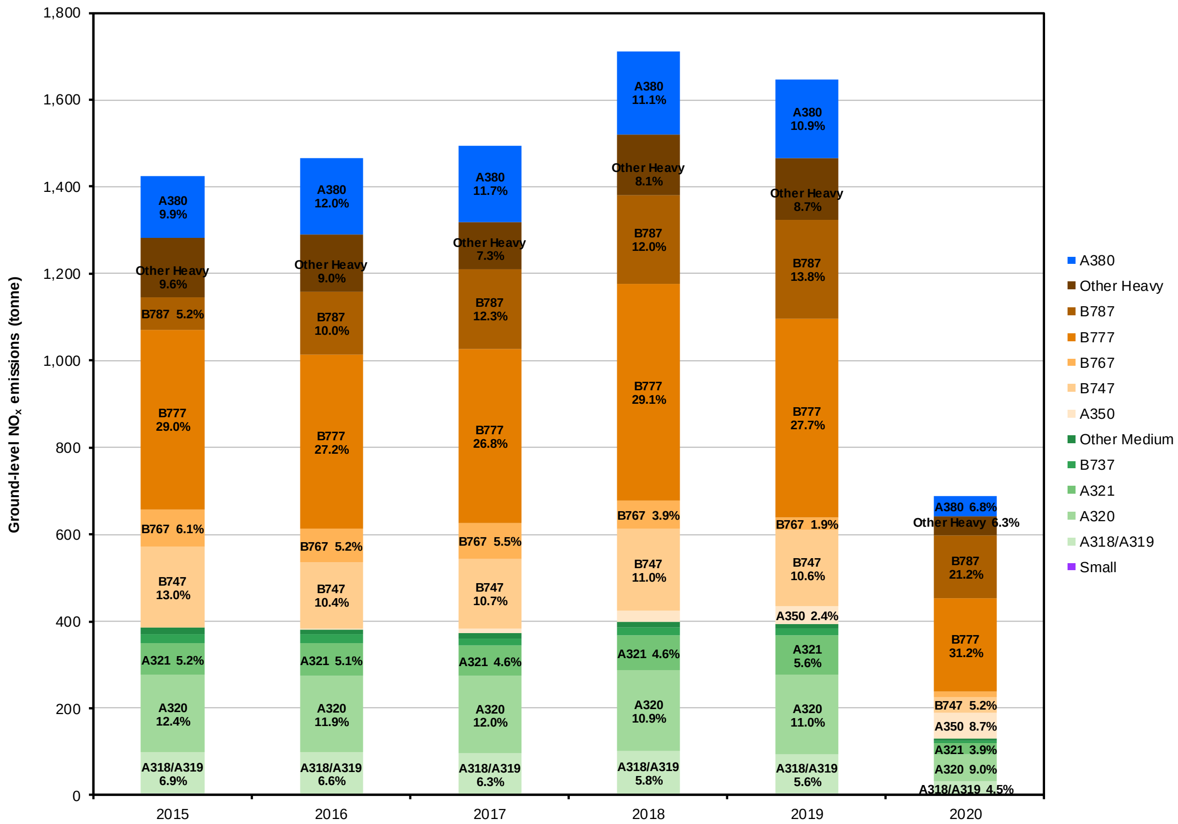
	NO_x emissions (kg/movement)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.69	0.68	0.35	0.35	0.30	0.30
Medium	1.30	1.31	1.30	1.40	1.38	1.20
A318/A319	1.16	1.20	1.15	1.25	1.27	1.14
A320	1.25	1.25	1.26	1.32	1.27	1.10
A321	1.72	1.73	1.80	2.02	1.90	1.62
B737	1.19	1.17	1.17	1.31	1.33	1.16
Others	1.63	1.58	1.40	1.43	1.28	1.12
Heavy	5.58	5.53	5.63	6.53	6.35	5.74
A350	5.59	4.80	4.02	5.11	5.29	5.69
B747	7.24	7.35	7.79	9.25	9.26	8.05
B767	3.08	2.96	3.45	3.98	3.35	3.09
B777	6.59	6.52	6.53	7.87	7.52	7.05
B787	4.76	5.31	5.03	4.98	5.00	4.89
Other	4.78	4.66	4.70	5.49	5.26	4.29
A380	9.55	9.60	9.47	11.41	11.25	10.39
Total	**3.00**	**3.09**	**3.14**	**3.58**	**3.44**	**3.36**

[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, increased year-on-year between the 2015 and 2018, but, with the propagation of newer low-NO_x aircraft types into the fleet, they decreased in 2019 and again in 2020.

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

Figure 6 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type: 2015 to 2020



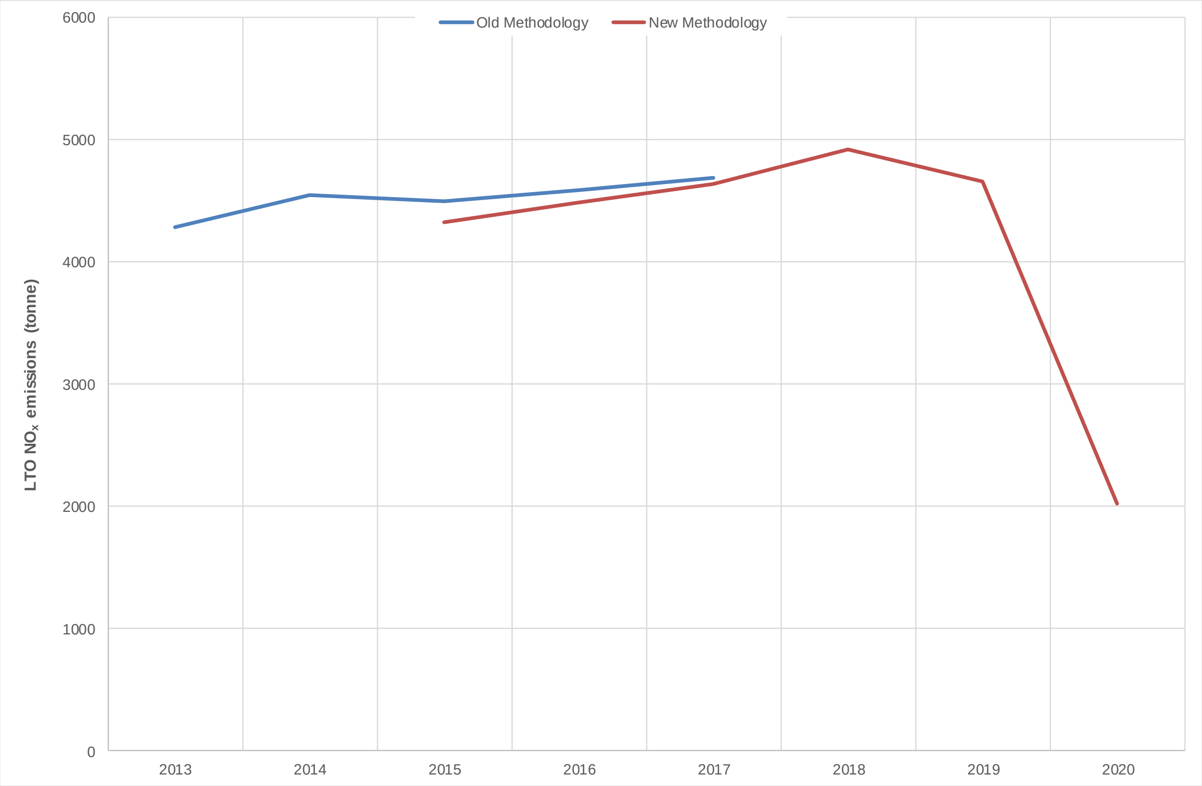
[1] Ground–level emissions from main engines only (omitting APU and engine testing)

3.1.1 Methodology updates

Figure 7 compares aircraft NO_x emissions calculated using the new methodology aligned to the Airport Expansion project with those of the 2013 inventory and dispersion modelling study and subsequent annual updates.

The new methodology yields slightly lower emissions in the overlapping years (-3.9% in 2015, -2.2% in 2016 and -1.1% in 2017). The main differences relate to updated times-in-mode, but the inclusion of reduced engine taxiing as a standard component of the methodology also contributes.

Figure 7 Comparison of LTO NO_x emissions: new methodology *vs* old methodology



3.2 PM_{10} and $PM_{2.5}$

Table 15 and Table 16 show airfield PM_{10} and $PM_{2.5}$ emissions broken down by source category, respectively.

Aircraft PM_{10} emissions remained relatively constant between 2015 and 2019. Emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic. The $PM_{2.5}$ trend follows a very similar pattern to PM_{10}.

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).

PM_{10} and $PM_{2.5}$ emissions from GSE have fallen year-on-year since 2015. This is due to the ground fleet turnover, with older equipment being retired and replaced with either newer equipment with tighter emissions standards or with electric equipment.

Emissions from stationary sources increased considerably in 2019, due to increased use of biomass as a fuel. The savings achieved in net CO_2 emissions from biomass burning come at a cost of increased PM_{10} emissions.

PM_{10} and $PM_{2.5}$ emissions in 2020 were heavily impacted by the COVID-19 pandemic.

Table 15 Breakdown of airfield PM_{10} emissions by source category: 2015 to 2020

Source Category	Annual PM_{10} emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Aircraft						
Ground-level						
Landing roll	0.46	0.50	0.50	0.41	0.39	0.18
Taxi-in	2.63	2.65	2.57	2.72	2.57	0.97
Taxi-out	4.61	4.60	4.57	4.70	4.57	1.74
Hold	4.45	4.74	4.63	4.42	4.30	1.18
Take-off roll	3.19	3.17	3.14	3.67	3.52	1.47
Brake wear	9.58	9.74	9.82	9.89	9.81	4.47
Tyre wear	6.38	6.51	6.59	6.64	6.57	3.05
APU	4.34	5.49	6.06	5.32	4.78	2.29
Engine testing[1]	0.06	0.06	0.06	0.06	0.06	0.06
Total ground-level	**35.69**	**37.45**	**37.94**	**37.83**	**36.55**	**15.39**
Elevated						
Approach	4.52	5.25	5.33	5.07	4.90	2.11
Initial climb	2.45	2.24	2.14	2.12	1.97	0.78
Climb out	5.66	5.62	5.63	5.67	5.28	2.08
Total elevated	**12.63**	**13.12**	**13.09**	**12.87**	**12.15**	**4.97**
Total aircraft	**48.33**	**50.57**	**51.03**	**50.69**	**48.71**	**20.36**
GSE[2]						
Exhaust	7.23	6.14	5.45	5.03	3.07	1.75
Fugitives	3.60	3.61	3.59	3.64	3.31	1.96
Total GSE	**10.83**	**9.75**	**9.04**	**8.67**	**6.37**	**3.71**

Source Category	Annual PM_{10} emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Stationary sources[3]						
Gas	N/A	N/A	N/A	N/A	1.05	0.90
Gas-oil	N/A	N/A	N/A	N/A	0.57	0.46
LPG	N/A	N/A	N/A	N/A	0.00	0.00
Biomass	N/A	N/A	N/A	N/A	37.66	45.48
(BA gas)	N/A	N/A	N/A	N/A	0.19	0.19
Total stationary	**8.68**	**6.29**	**4.85**	**7.80**	**39.47**	**47.03**
Total airfield	**67.83**	**66.61**	**64.92**	**67.16**	**94.55**	**71.11**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018.

Table 16 Breakdown of airfield $PM_{2.5}$ emissions by source category: 2015 to 2020

Source Category	Annual $PM_{2.5}$ emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Aircraft						
Ground-level						
Landing roll	0.46	0.50	0.50	0.41	0.39	0.18
Taxi-in	2.63	2.65	2.57	2.72	2.57	0.97
Taxi-out	4.61	4.60	4.57	4.70	4.57	1.74
Hold	4.45	4.74	4.63	4.42	4.30	1.18
Take-off roll	3.19	3.17	3.14	3.67	3.52	1.47
Brake wear	3.81	3.88	3.91	3.94	3.90	1.78
Tyre wear	4.47	4.56	4.61	4.65	4.60	2.14
APU	4.34	5.49	6.06	5.32	4.78	2.29
Engine testing[1]	0.06	0.06	0.06	0.06	0.06	0.06
Total ground-level	**28.01**	**29.64**	**30.05**	**29.88**	**28.68**	**11.78**
Elevated						
Approach	4.52	5.25	5.33	5.07	4.90	2.11
Initial climb	2.45	2.24	2.14	2.12	1.97	0.78
Climb out	5.66	5.62	5.63	5.67	5.28	2.08
Total elevated	**12.63**	**13.12**	**13.09**	**12.87**	**12.15**	**4.97**
Total aircraft	**40.64**	**42.75**	**43.14**	**42.75**	**40.83**	**16.75**
GSE[2]						
Exhaust	6.82	5.80	5.14	4.75	2.90	1.66
Fugitives	1.69	1.69	1.69	1.71	1.55	0.92
Total GSE	**8.51**	**7.49**	**6.83**	**6.46**	**4.45**	**2.59**

Source Category	Annual $PM_{2.5}$ emissions (tonnes)					
	2015	2016	2017	2018	2019	2020
Stationary sources[3]						
Gas	N/A	N/A	N/A	N/A	1.05	0.90
Gas-oil	N/A	N/A	N/A	N/A	0.57	0.46
LPG	N/A	N/A	N/A	N/A	0.00	0.00
Biomass	N/A	N/A	N/A	N/A	36.87	44.53
(BA gas)	N/A	N/A	N/A	N/A	0.19	0.19
Total stationary	**6.36**	**4.83**	**N/A**	**N/A**	**38.68**	**46.08**
Total airfield	**55.51**	**55.07**	**N/A**	**N/A**	**83.96**	**65.42**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018. $PM_{2.5}$ emissions not calculated for 2017 or 2018.

Table 17 shows the values of annual aircraft LTO PM_{10} and $PM_{2.5}$ emissions normalised by the number of passengers and movements. PM_{10} and $PM_{2.5}$ emissions per passenger are highest in 2020. However, this year is heavily affected by reduced passenger load factors as a result of the COVID-19 pandemic. PM_{10} and $PM_{2.5}$ per movement remained relatively constant over the period 2015 and 2020.

Table 17 LTO PM emissions per passenger and per movement: 2015 to 2020

	2015	2016	2017	2018	2019	2020
LTO PM_{10} (tonnes per year)	48.33	50.57	51.03	50.69	48.71	20.36
LTO $PM_{2.5}$ (tonnes per year)	40.64	42.75	43.14	42.75	40.83	16.75
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11
LTO PM_{10} (g per passenger[1])	0.64	0.67	0.65	0.63	0.60	0.92
LTO $PM_{2.5}$ (g per passenger[1])	0.54	0.56	0.55	0.53	0.50	0.76
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73
LTO PM_{10} (kg per movement[2])	0.10	0.11	0.11	0.11	0.10	0.10
LTO $PM_{2.5}$ (kg per movement[2])	0.09	0.09	0.09	0.09	0.09	0.08

[1] Excludes transit passengers
[2] ATMs and non-ATMs

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) remained relatively constant between 2015 and 2019. Emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

For PM, non-exhaust emissions (aircraft brake and tyre wear) are a significant contributor to the ground-level aircraft emissions, together accounting for between 40% and 50% of the ground-level PM_{10} emissions (between 20% and 30% for $PM_{2.5}$).

Table 18 gives a breakdown of ground-level aircraft exhaust PM emissions (omitting brake and tyre wear, APUs and engine testing) by aircraft type. As expected from the movement breakdowns in Table 1, the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction (approximately 40%) of the emissions in all years. The larger aircraft types, B747, B777 and A380, together contribute over one third of the emissions in each year, despite accounting for less than a quarter of the total movements.

Table 18 also gives ground-level emissions per movement (excluding APU, engine testing and brake and tyre wear emissions) for each aircraft type. 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 those for the single-aisle jets. However, this pattern is changing, with newer aircraft types entering the fleet and fewer older aircraft remaining.

Table 18 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type: 2015 to 2020

(a)

	PM emissions (tonnes/year)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.08	0.06	0.02	0.01	0.03	0.01
Medium	7.19	7.32	7.06	7.18	6.82	2.17
A318/A319	2.24	2.33	2.25	2.36	2.19	0.73
A320	3.34	3.35	3.32	3.28	3.04	1.03
A321	1.18	1.24	1.14	1.23	1.29	0.29
B737	0.29	0.29	0.23	0.21	0.18	0.07
Others	0.13	0.10	0.11	0.11	0.11	0.04
Heavy	7.10	7.04	7.13	7.54	7.36	3.06
A350	0.00	0.02	0.08	0.17	0.26	0.33
B747	1.83	1.51	1.59	1.70	1.62	0.36
B767	0.95	0.90	0.89	0.58	0.41	0.14
B777	2.89	2.86	2.89	3.20	3.00	1.24
B787	0.36	0.64	0.83	0.93	1.04	0.64
Other	1.08	1.11	0.85	0.97	1.04	0.35
A380	0.97	1.23	1.20	1.18	1.14	0.29
Total	**15.34**	**15.66**	**15.41**	**15.92**	**15.34**	**5.53**

(b)

	PM emissions (%)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.5	0.4	0.1	0.1	0.2	0.1
Medium	46.9	46.8	45.8	45.1	44.4	39.2
A318/A319	14.6	14.9	14.6	14.8	14.3	13.3
A320	21.8	21.4	21.6	20.6	19.8	18.7
A321	7.7	7.9	7.4	7.7	8.4	5.3
B737	1.9	1.9	1.5	1.3	1.2	1.2
Others	0.9	0.7	0.7	0.7	0.7	0.8
Heavy	46.3	45.0	46.3	47.4	48.0	55.4
A350	0.0	0.1	0.5	1.1	1.7	5.9
B747	11.9	9.7	10.3	10.7	10.5	6.5
B767	6.2	5.8	5.8	3.6	2.6	2.5
B777	18.8	18.2	18.7	20.1	19.6	22.5
B787	2.3	4.1	5.4	5.8	6.8	11.7
Other	7.0	7.1	5.5	6.1	6.7	6.4
A380	6.3	7.9	7.8	7.4	7.4	5.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

(c)

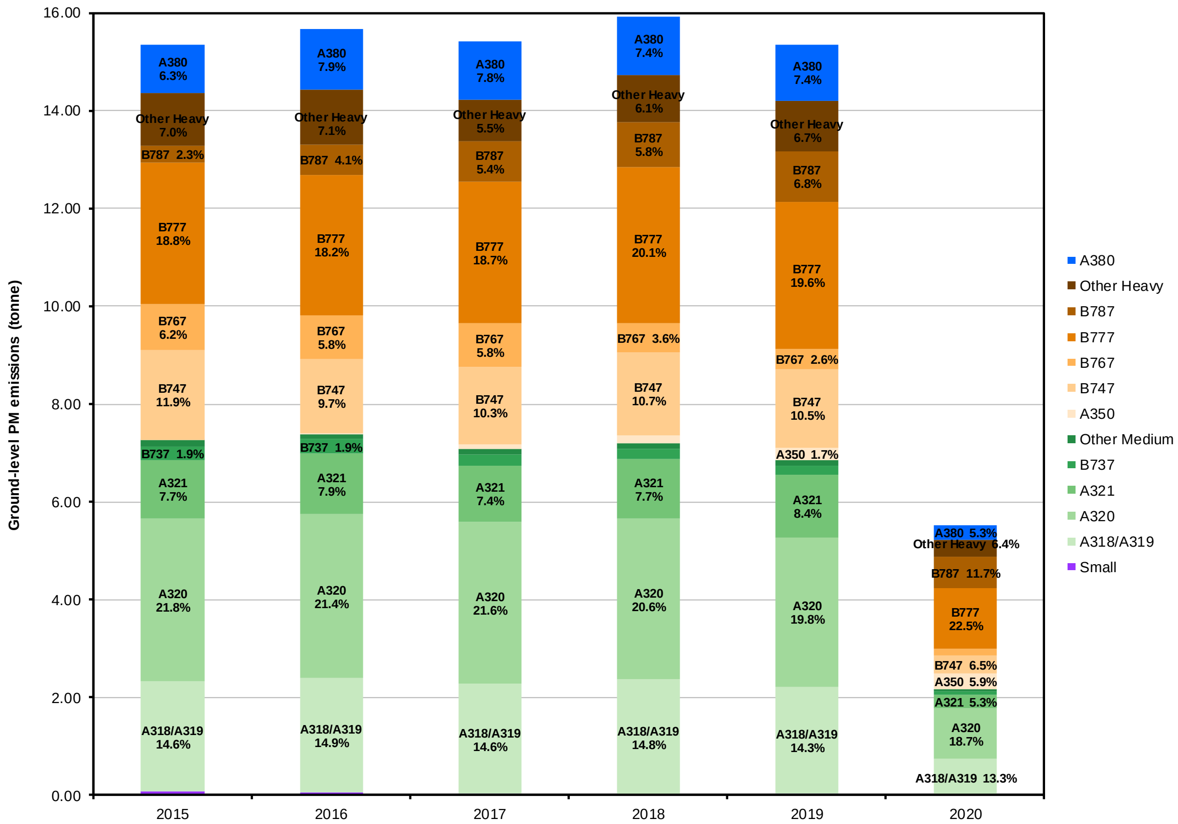
	PM emissions (g/movement)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	23.20	24.53	5.13	2.73	3.21	2.98
Medium	24.38	25.27	24.78	25.27	24.03	19.88
A318/A319	26.53	28.65	27.65	29.38	30.25	26.82
A320	23.68	23.90	23.51	23.15	21.35	18.48
A321	27.65	28.88	29.63	31.29	26.74	17.37
B737	15.72	15.71	15.38	14.89	16.74	13.81
Others	16.49	16.09	13.33	12.08	11.59	10.26
Heavy	44.11	42.83	42.42	43.91	43.56	34.40
A350	28.18	29.26	29.93	33.88	34.16	31.14
B747	71.15	73.27	77.40	83.72	85.50	80.56
B767	33.42	34.76	37.43	35.05	44.13	38.10
B777	46.09	46.63	47.11	50.55	49.51	40.65
B787	22.81	23.09	22.67	22.56	22.94	21.64
Other	37.78	39.39	36.71	38.07	38.03	34.79
A380	65.50	67.57	64.74	70.87	71.09	65.69
Total	32.35	32.97	32.39	33.32	32.10	27.00

[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, remained relatively constant between 2015 and 2019. Emissions in 2020 were heavily impacted by the COVID-19 pandemic.

Figure 8 shows the trend in ground-level aircraft PM emissions broken down by aircraft type.

Figure 8 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type: 2015 to 2020



[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)

3.2.1 Methodology updates

Figure 9 compares aircraft PM_{10} emissions calculated using the new methodology aligned to the Airport Expansion project with those of the 2013 inventory and dispersion modelling study and subsequent annual updates. Figure 10 performs the same comparison for $PM_{2.5}$.

The new methodology yields slightly lower PM_{10} emissions in the overlapping years (-2.5% in 2015, -1.5% in 2016 and -0.4% in 2017). The main differences relate to updated times-in-mode, but the inclusion of reduced engine taxiing as a standard component of the methodology also contributes.

Similarly, for $PM_{2.5}$ the new methodology yields slightly lower emissions in the overlapping years (-2.9% in 2015, -1.8% in 2016 and -0.5% in 2017).

Figure 9 Comparison of LTO PM_{10} emissions: new methodology *vs* old methodology

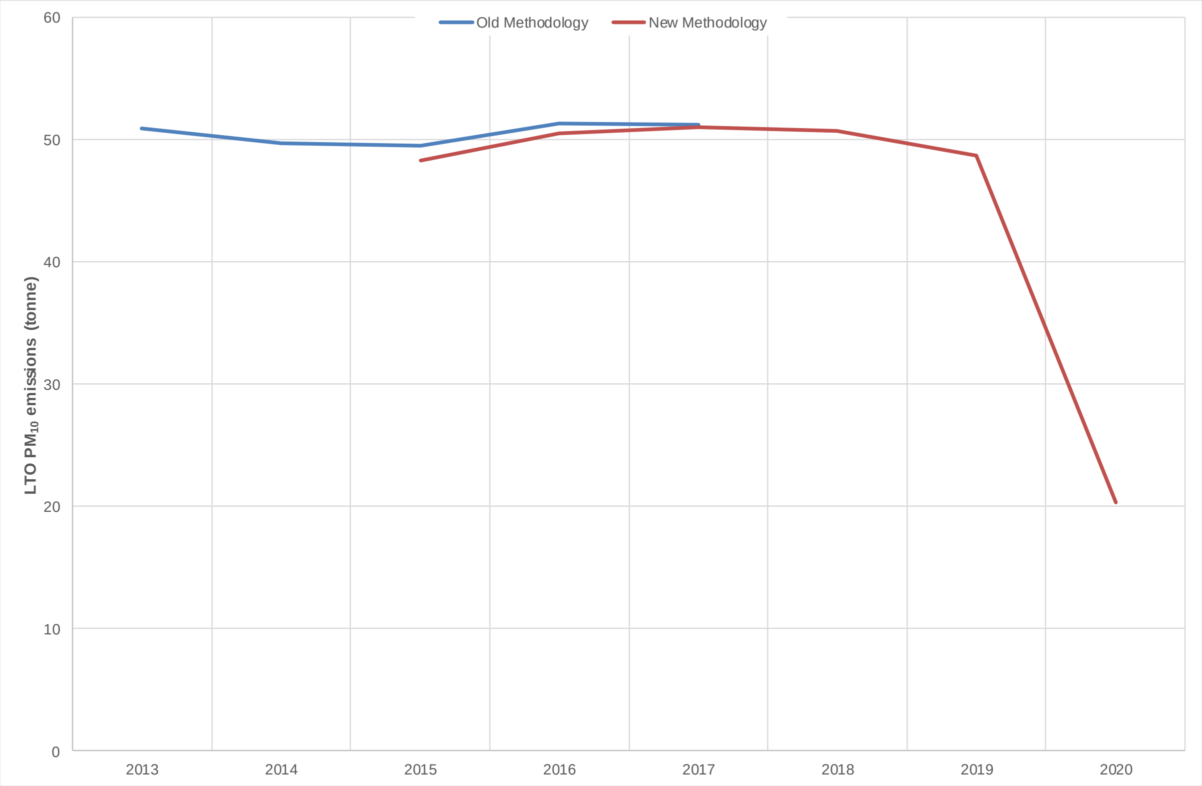
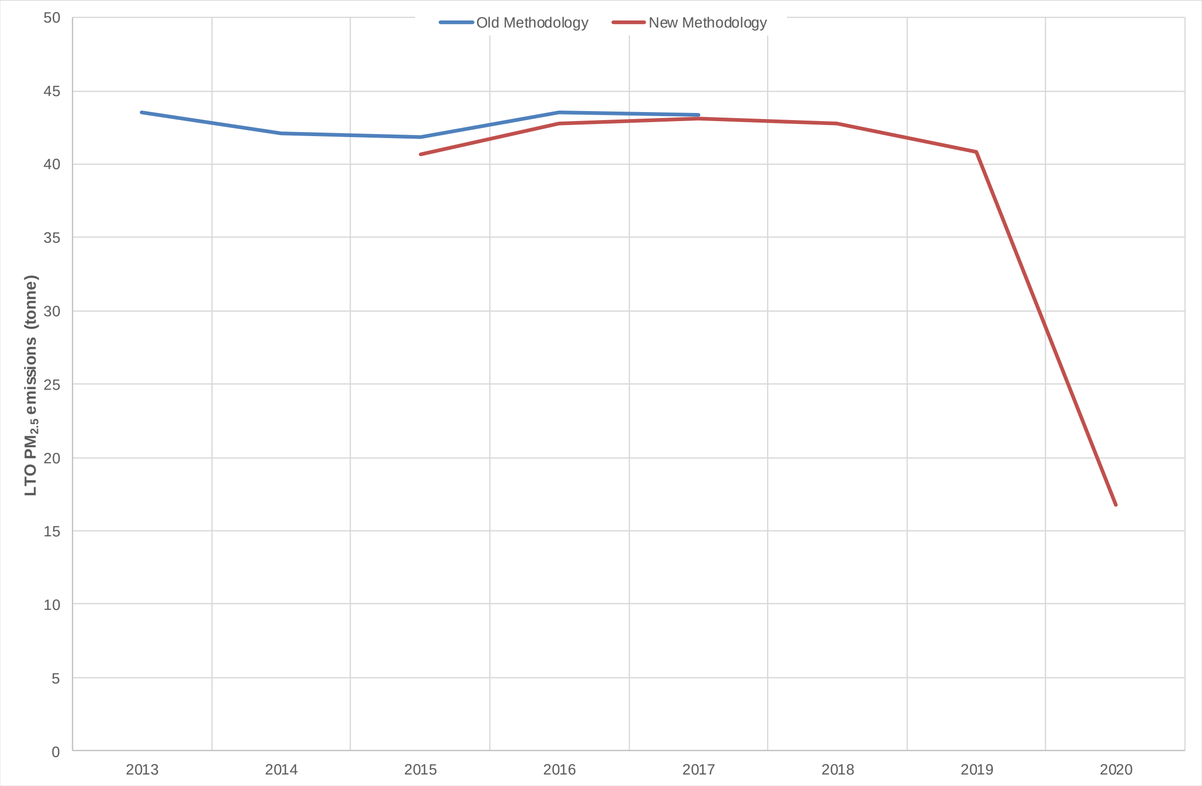


Figure 10 Comparison of LTO $PM_{2.5}$ emissions: new methodology *vs* old methodology



3.3 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[5] (3.15 kg/kg fuel). Therefore, the CO_2 emissions are calculated simply by multiplying the calculated fuel burn by that emissions index. Table 19 shows airfield emissions of CO_2 broken down by source category. For aircraft emissions these are the phases of the LTO cycle as reported in the 2013 inventory and dispersion modelling study and the subsequent annual updates.

The calculated total aircraft CO_2 emissions (up to 3,000 feet) increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 4% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer more efficient aircraft types in into the fleet, particularly the A320 neo and A321 neo. There is also some year-on-year variation due to variations in operational data, such as APU running times and taxiing times, that influence emissions.

GSE emissions remained relatively constant between 2015 and 2019. Emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

[5] Strictly, the emissions index for CO_2 is a function of the chemistry of the fuel; it is slightly different for other fuels such as gasoline or diesel.

CO_2 emissions from biomass burning are not included in the stationary source totals as they are not a fossil fuel. Emissions from other fuels remained relatively constant between 2015 and 2020. However, CO_2 emissions were not calculated for 2017 or 2018.

CO_2 emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

Table 19 Breakdown of airfield CO_2 emissions by mode: 2015 to 2020

Mode	Annual CO_2 emissions (kilotonnes)					
	2015	2016	2017	2018	2019	2020
Aircraft						
Ground-level						
Landing roll	18.34	20.24	20.89	16.62	16.15	7.40
Taxi-in	92.62	93.84	92.44	99.71	95.66	38.84
Taxi-out	163.89	163.28	163.24	169.74	166.65	67.80
Hold	154.11	164.67	161.66	158.54	156.98	45.84
Take-off roll	96.57	97.06	97.77	120.33	117.52	51.92
APU	84.32	103.00	118.63	104.30	90.70	44.61
Engine testing[1]	1.21	1.21	1.21	1.21	1.21	1.21
Total ground-level	**611.06**	**643.30**	**655.83**	**670.46**	**644.87**	**257.62**
Elevated						
Approach	152.66	177.16	182.40	176.54	175.12	77.36
Initial climb	76.05	69.80	67.33	68.30	64.65	27.39
Climb out	169.49	170.31	171.51	177.21	169.56	70.26
Total elevated	**398.20**	**417.27**	**421.23**	**422.05**	**409.34**	**175.01**
Total aircraft	**1009.26**	**1060.57**	**1077.07**	**1092.51**	**1054.21**	**432.63**
GSE[2]	**29.88**	**29.88**	**29.88**	**30.43**	**28.52**	**16.45**

Mode	Annual CO_2 emissions (kilotonnes)					
	2015	2016	2017	2018	2019	2020
Stationary Sources[3]						
Gas	N/A	N/A	N/A	N/A	22.24	16.89
Gas-oil	N/A	N/A	N/A	N/A	1.61	1.29
LPG	N/A	N/A	N/A	N/A	0.04	0.00
Biomass	-	-	-	-	-	-
(BA gas)	N/A	N/A	N/A	N/A	17.36	17.36
Total Stationary	**38.76**	**37.45**	**N/A**	**N/A**	**41.23**	**35.53**
Total Airfield	**1077.89**	**1127.90**	**N/A**	**N/A**	**1123.97**	**484.62**

[1] Engine testing emissions have not been recalculated since 2013. However, they represent a very small fraction of the total.
[2] GSE emissions for 2015 and 2016 are based on 2017 fuel data.
[3] Breakdown by fuel not available for 2015 to 2018. CO_2 emissions not calculated for 2017 or 2018. CO_2 emissions from biomass not included.

Table 20 shows the values of annual aircraft LTO CO_2 emissions normalised by the number of passengers and movements. The CO_2 per passenger s highest in 2020. However, this year is heavily affected by reduced passenger load factors as a result of the COVID-19 pandemic. The CO_2 per movement increased year-on-year between 2015 and 2018 in line with the shift towards larger aircraft. However, this trend did not continue into 2019, mainly due to the propagating of newer cleaner aircraft types into the fleet

Table 20 LTO CO_2 emissions per passenger and per movement: 2015 to 2020

	2015	2016	2017	2018	2019	2020
LTO CO_2 (kilotonnes per year)	1009.26	1060.57	1077.07	1092.51	1054.21	432.63
Passengers[1] (mppa)	74.95	75.67	77.99	80.10	80.89	22.11
LTO CO_2 (kg per passenger[1])	13.47	14.02	13.81	13.64	13.03	19.57
Movements[2] (1000s)	474.09	474.96	475.78	477.60	478.06	204.73
LTO CO_2 (tonnes per movement[2])	2.13	2.23	2.26	2.29	2.21	2.11

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Table 21 gives a breakdown of LTO aircraft CO_2 emissions (omitting APUs and engine testing) by aircraft type. As expected from the movement breakdowns in Table 1, the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction (approximately 30%) of the emissions in all years except 2020. However, the larger aircraft types, B747, B777 and A380, together contribute almost half of the emissions in each year, despite accounting for less than a quarter of the total movements.

Table 21 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 3,000 feet 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 21 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type: 2015 to 2020

(a)

	CO_2 emissions (kilotonnes/year)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	2.34	1.72	1.37	1.46	2.45	0.66
Medium	305.18	311.29	306.78	310.66	306.11	104.48
A318/A319	81.48	82.95	82.37	83.36	76.17	26.60
A320	143.97	148.34	151.19	151.98	149.20	51.96
A321	51.32	53.13	48.46	51.49	59.85	17.81
B737	18.67	19.03	15.54	14.54	11.62	4.63
Others	9.75	7.83	9.22	9.29	9.27	3.48
Heavy	530.69	536.04	544.08	575.88	559.81	257.01
A350	0.16	1.93	7.38	14.43	21.55	28.90
B747	122.82	101.93	102.84	105.14	98.90	21.59
B767	61.62	54.66	51.60	37.95	19.87	7.78
B777	220.66	221.56	222.54	240.29	227.17	104.17
B787	37.26	68.95	89.96	99.95	110.92	68.92
Other	88.17	87.02	69.76	78.14	81.41	25.66
A380	85.52	107.31	104.99	98.99	93.94	24.67
Total	**923.73**	**956.36**	**957.23**	**986.99**	**962.30**	**386.82**

(b)

	CO_2 emissions (%)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.3	0.2	0.1	0.1	0.3	0.2
Medium	33.0	32.5	32.0	31.5	31.8	27.0
A318/A319	8.8	8.7	8.6	8.4	7.9	6.9
A320	15.6	15.5	15.8	15.4	15.5	13.4
A321	5.6	5.6	5.1	5.2	6.2	4.6
B737	2.0	2.0	1.6	1.5	1.2	1.2
Others	1.1	0.8	1.0	0.9	1.0	0.9
Heavy	57.5	56.0	56.8	58.3	58.2	66.4
A350	0.0	0.2	0.8	1.5	2.2	7.5
B747	13.3	10.7	10.7	10.7	10.3	5.6
B767	6.7	5.7	5.4	3.8	2.1	2.0
B777	23.9	23.2	23.2	24.3	23.6	26.9
B787	4.0	7.2	9.4	10.1	11.5	17.8
Other	9.5	9.1	7.3	7.9	8.5	6.6
A380	9.3	11.2	11.0	10.0	9.8	6.4
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

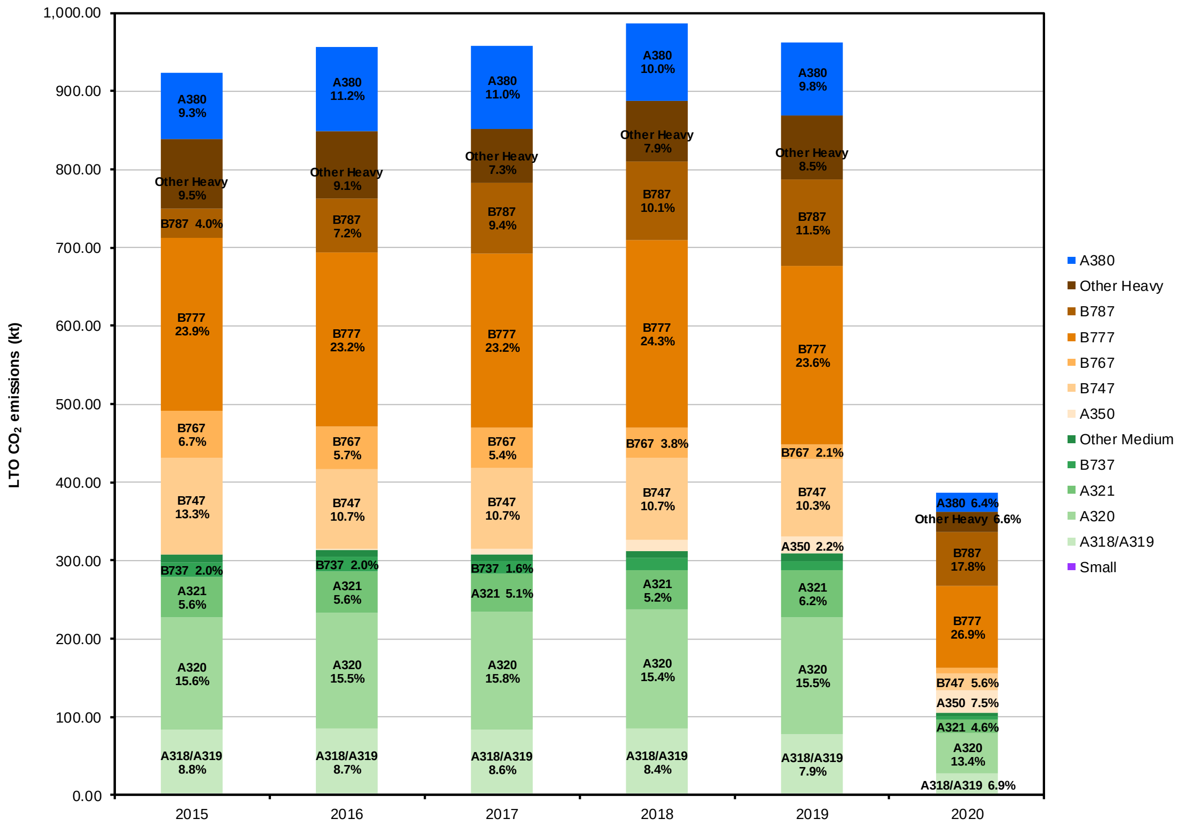
(c)

	CO_2 emissions (tonnes/movement)					
Aircraft Type	2015	2016	2017	2018	2019	2020
Small	0.65	0.69	0.32	0.28	0.26	0.28
Medium	1.04	1.07	1.08	1.09	1.08	0.96
A318/A319	0.97	1.02	1.01	1.04	1.05	0.97
A320	1.02	1.06	1.07	1.07	1.05	0.93
A321	1.20	1.23	1.26	1.31	1.24	1.07
B737	1.02	1.02	1.02	1.04	1.08	0.96
Others	1.19	1.20	1.08	1.02	0.95	0.83
Heavy	3.30	3.26	3.24	3.35	3.31	2.89
A350	2.71	2.70	2.63	2.86	2.85	2.75
B747	4.79	4.93	5.00	5.19	5.23	4.83
B767	2.17	2.11	2.17	2.29	2.16	2.17
B777	3.52	3.62	3.63	3.80	3.75	3.41
B787	2.39	2.50	2.47	2.42	2.44	2.31
Other	3.08	3.08	3.00	3.08	2.99	2.54
A380	5.77	5.88	5.68	5.93	5.87	5.51
Total	**1.95**	**2.01**	**2.01**	**2.07**	**2.01**	**1.89**

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

Figure 11 shows the trend in LTO aircraft CO_2 emissions broken down by aircraft type.

Figure 11 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type: 2015 to 2020



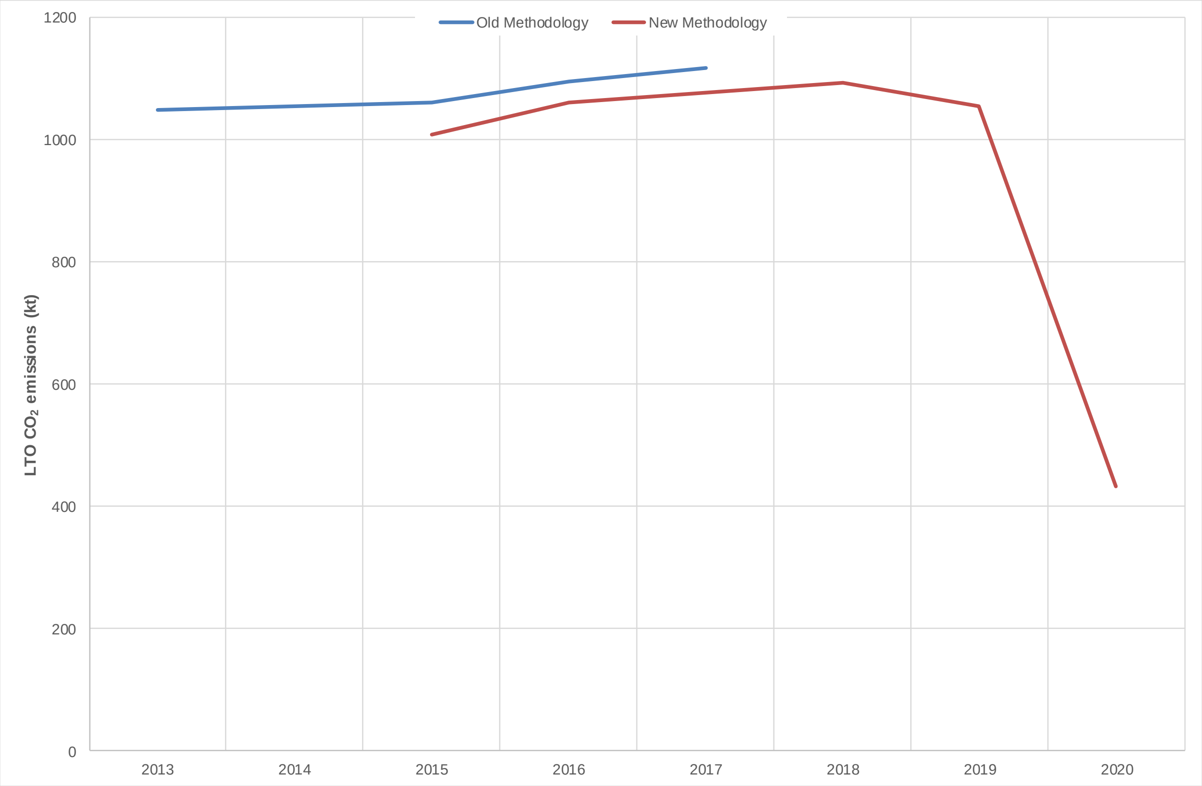
[1] LTO emissions from main engines only (omitting APU and engine testing)

3.3.1 Methodology updates

Figure 12 compares aircraft CO_2 emissions calculated using the new methodology aligned to the Airport Expansion project with those of the 2013 inventory and dispersion modelling study and subsequent annual updates.

The new methodology yields slightly lower emissions in the overlapping years (-4.8% in 2015, -3.2% in 2016 and -3.6% in 2017). The main differences relate to updated times-in-mode and the inclusion of reduced engine taxiing as a standard component of the methodology.

Figure 12 Comparison of LTO CO_2 emissions: new methodology *vs* old methodology



4 Summary and conclusions

The total annual emissions of NO_x, PM_{10}, $PM_{2.5}$ and CO_2 on the airfield have been calculated for the calendar years 2019 and 2020, based on detailed flight records held by Heathrow Airport. These have been presented along with inventories for 2015 to 2018 that were produced for the Airport Expansion Consultation. This updates the published Heathrow Airport emissions inventories for 2015, 2016 and 2017 that covered aircraft emissions only.

This update expands the scope of Heathrow Airport's emissions inventories to include all airfield sources and updates the methodology to align with that of the Airport Expansion Consultation.

The update makes full use of year-specific operational data rather than rolling data that are not expected to change greatly from year-to-year, as was the case for previous updates.

Table 22 shows some summary information about total emissions from the LTO (including APUs, engine testing and brake and tyre wear), while Table 23 presents the same information for ground-level emissions only.

Up until 2019, the number of aircraft movements has remained broadly constant, reflecting the fact that the airport was operating close to the cap of 480,000 ATMs (refer to Figure 1). Despite this, the number of passengers shows a steady increase over the same period, accommodated by a larger number of passengers per movement on average (Figure 2). In 2020 there was a dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

Aircraft NO_x emissions in the Landing and Take-Off (LTO) cycle (up to 3,000 feet altitude) increased year-on-year between 2015 and 2018, broadly in line with passenger numbers. However, in 2019 aircraft emissions were 5% lower than their 2018 peak despite continued passenger growth. This is mainly due to the propagating of newer low-NO_x aircraft types in into the fleet.

For PM_{10} and $PM_{2.5}$, emissions in the LTO cycle remained relatively constant between 2015 and 2019.

For CO_2, emissions in the LTO cycle followed a similar patter to NO_x, increasing year-on-year between 2015 and 2018, with aircraft emissions in 2019 4% lower than their 2018 peak due to the propagating of newer more efficient aircraft types in into the fleet.

For all pollutants, emissions in 2020 were heavily impacted by the dramatic downturn in both movements and passengers due to the COVID-19 pandemic.

The calculated value of ground-level aircraft NO_x emissions (which are more important than elevated emissions from the perspective of local air quality) also peaked in 2018. The calculated value of ground-level aircraft PM_{10} and $PM_{2.5}$ emissions (including brake and tyre wear, APU and engine testing emissions) remained relatively constant between 2015 and 2019. Ground-level emissions are plotted in Figure 13.

Figure 14 shows the ground-level NO_x emissions per movement and per passenger. The calculated values of NO_x emissions per movement in 2018 stands clearly above the long-term trend, which is gently increasing. However, the reasons are far from obvious and are likely a combination of many factors.

Figure 15 and Figure 16 show the ground-level emissions per movement and per passenger, for PM_{10} and $PM_{2.5}$, respectively. Emissions per movement are highest in 2017.

Note that the vertical scales in Figure 14 to Figure 16 are chosen to exaggerate the trends, which are typically only a few percent per year.

Table 22 Summary of total LTO emissions

	2015	2016	2017	2018	2019	2020
NO_x (t/year)	4321.52	4487.28	4634.87	4919.82	4657.52	2017.87
NO_x (g/pax[1])	57.66	59.30	59.43	61.42	57.58	91.27
NO_x (kg/mvt[2])	9.12	9.45	9.74	10.30	9.74	9.86
PM_{10} (t/year)	48.33	50.57	51.03	50.69	48.71	20.36
PM_{10} (g/pax[1])	0.64	0.67	0.65	0.63	0.60	0.92
PM_{10} (kg/mvt[2])	0.10	0.11	0.11	0.11	0.10	0.10
$PM_{2.5}$ (t/year)	40.64	42.75	43.14	42.75	40.83	16.75
$PM_{2.5}$ (g/pax[1])	0.54	0.56	0.55	0.53	0.50	0.76
$PM_{2.5}$ (kg/mvt[2])	0.09	0.09	0.09	0.09	0.09	0.08
CO_2 (kt/year)	1009.26	1060.57	1077.07	1092.51	1054.21	432.63
CO_2 (kg/pax[1])	13.47	14.02	13.81	13.64	13.03	19.57
CO_2 (t/mvt[2])	2.13	2.23	2.26	2.29	2.21	2.11

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Table 23 Summary of ground-level emissions

	2015	2016	2017	2018	2019	2020
NO_x (t/year)	1679.94	1782.89	1829.73	2013.29	1906.85	826.23
NO_x (g/pax[1])	22.41	23.56	23.46	25.13	23.57	37.37
NO_x (kg/mvt[2])	3.54	3.75	3.85	4.22	3.99	4.04
PM_{10} (t/year)	35.69	37.45	37.94	37.83	36.55	15.39
PM_{10} (g/pax[1])	0.48	0.49	0.49	0.47	0.45	0.70
PM_{10} (kg/mvt[2])	0.08	0.08	0.08	0.08	0.08	0.08
$PM_{2.5}$ (t/year)	28.01	29.64	30.05	29.88	28.68	11.78
$PM_{2.5}$ (g/pax[1])	0.37	0.39	0.39	0.37	0.35	0.53
$PM_{2.5}$ (kg/mvt[2])	0.06	0.06	0.06	0.06	0.06	0.06

[1] Excludes transit passengers
[2] ATMs and non-ATMs

Figure 13 Ground-level emissions of NO_x, PM_{10} and $PM_{2.5}$

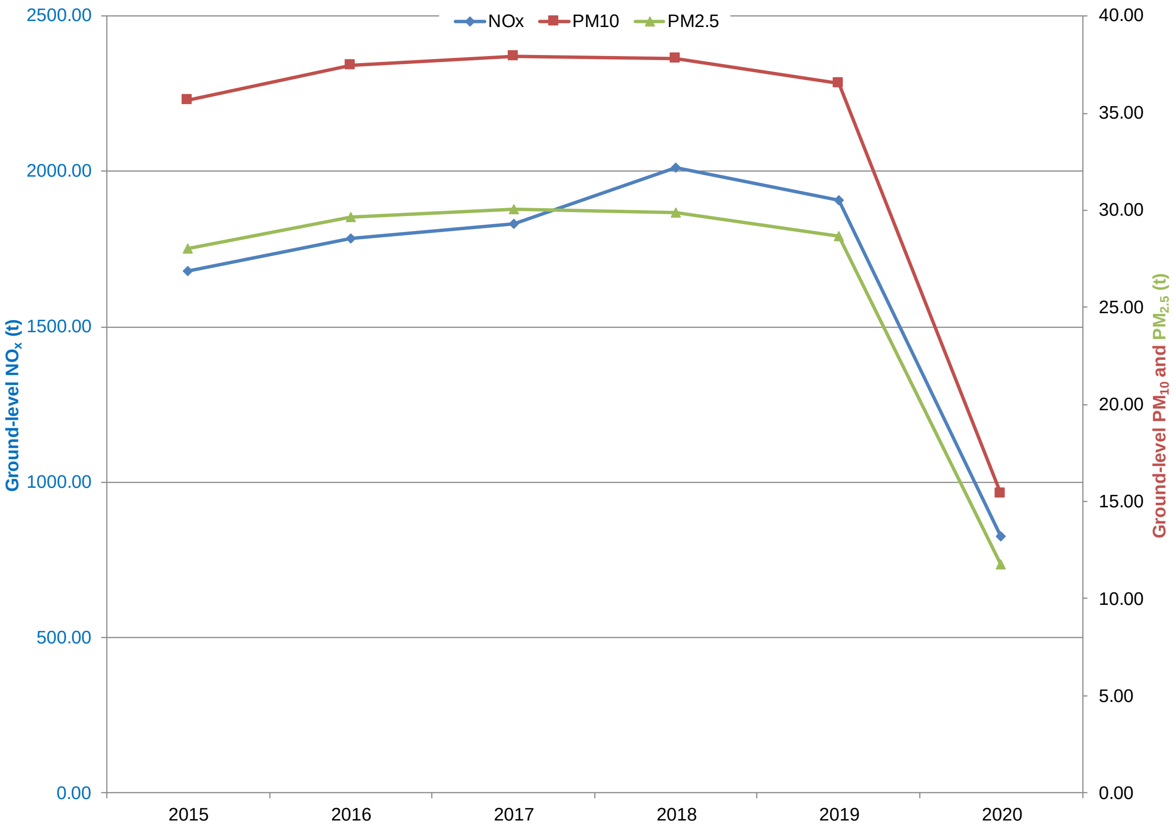


Figure 14 Ground-level NO_x emissions per movement and per passenger

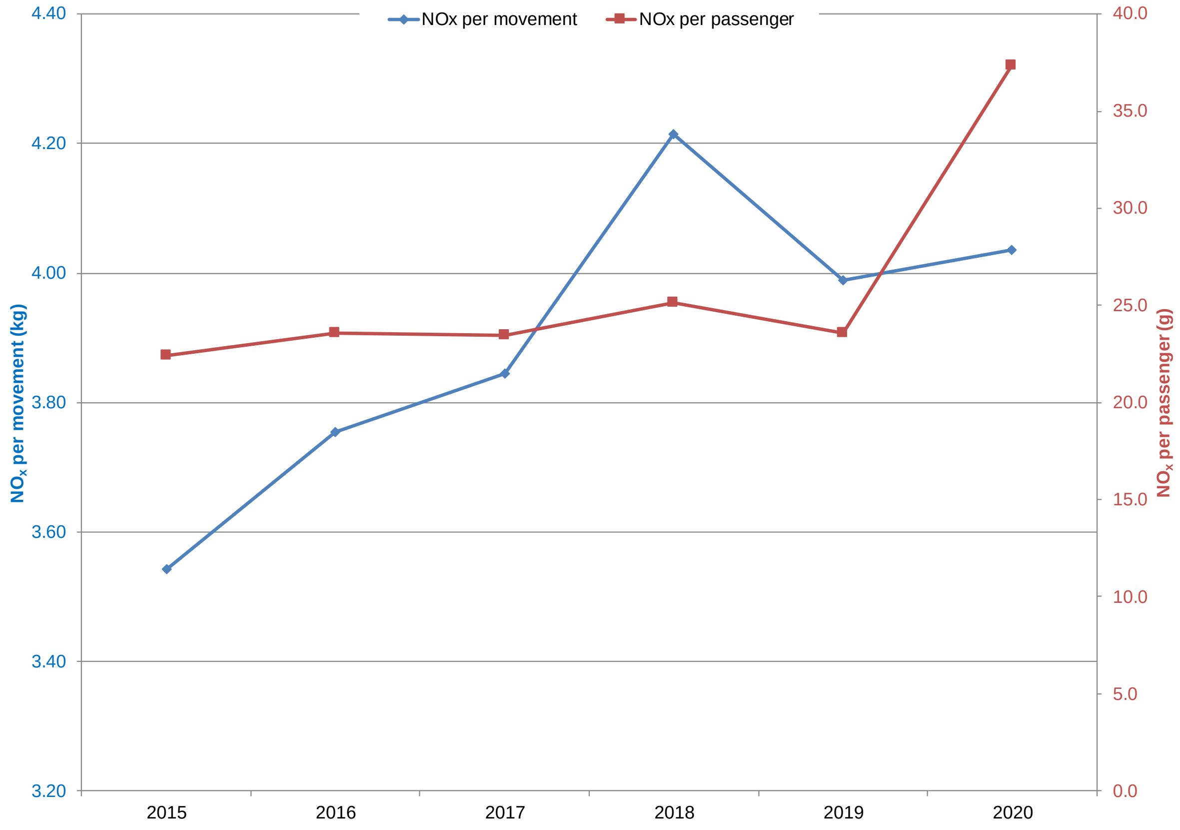


Figure 15 Ground-level PM_{10} emissions per movement and per passenger

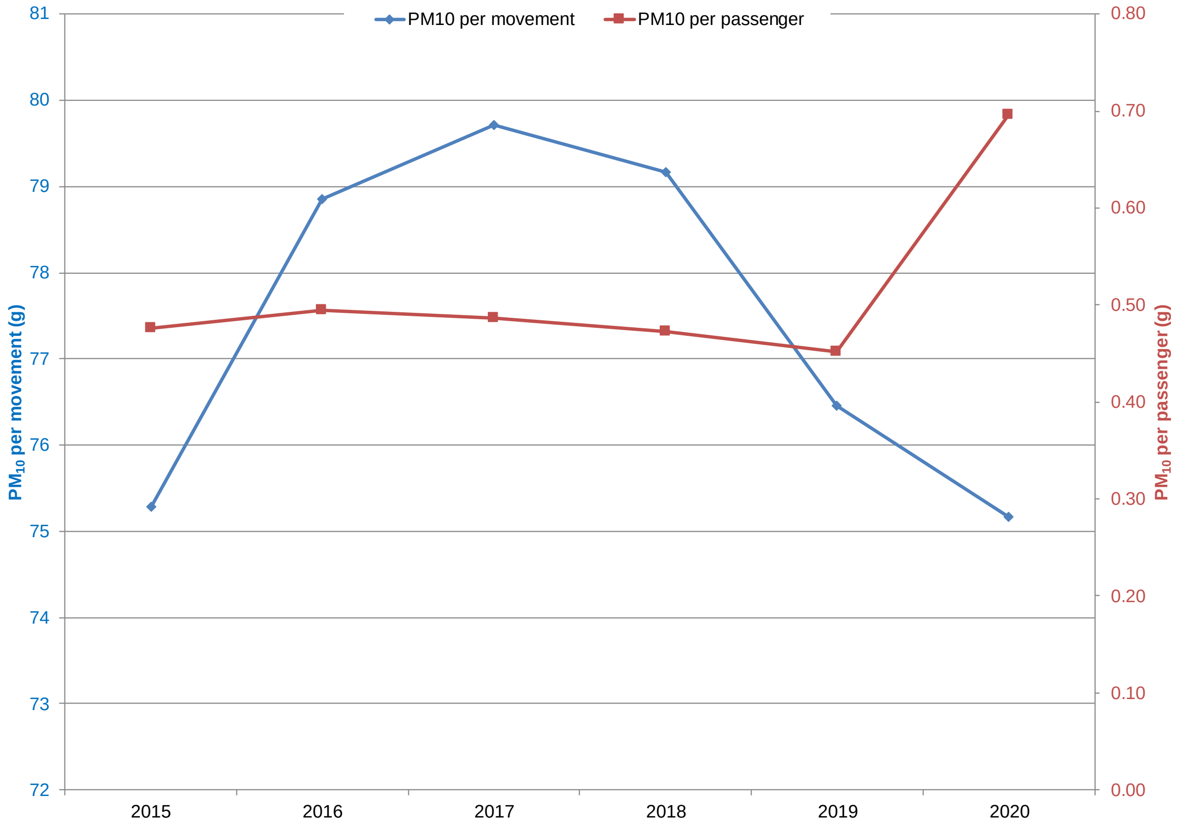
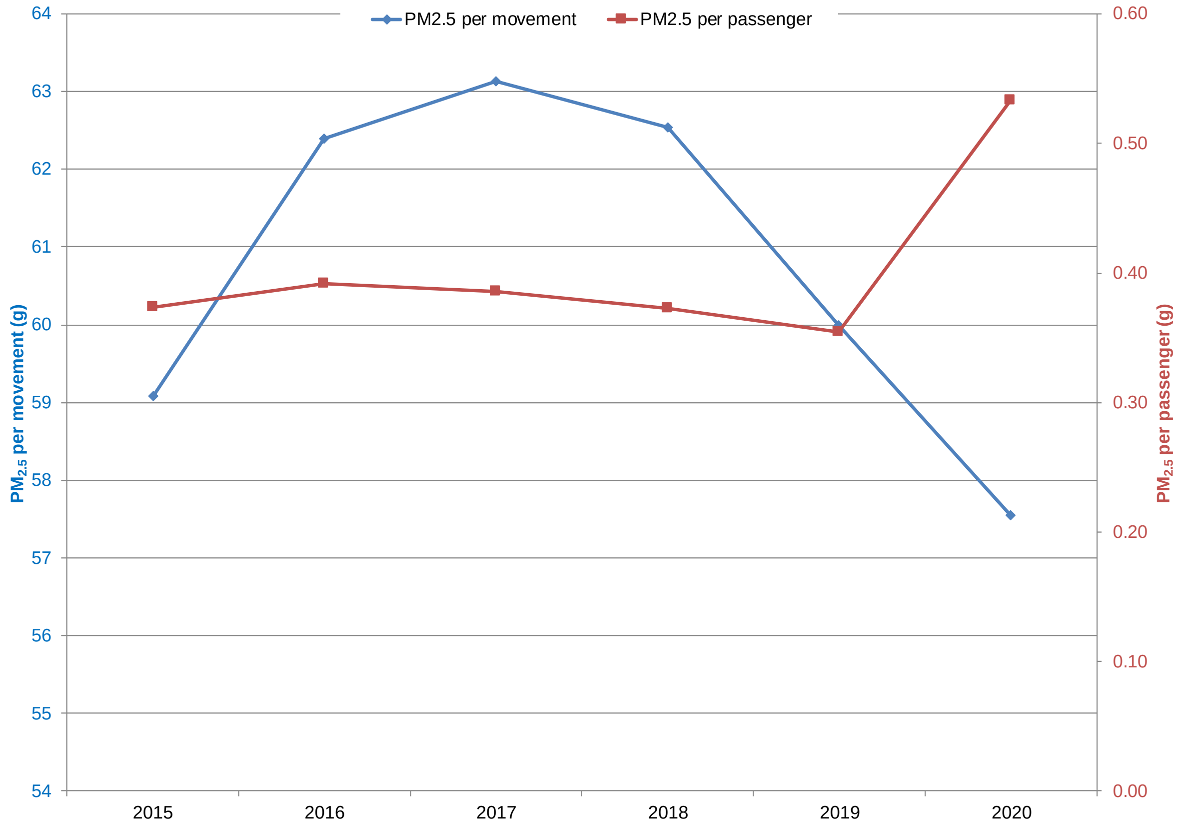


Figure 16 Ground-level $PM_{2.5}$ emissions per movement and per passenger



5 Recommendations

Take-off roll emissions are highly sensitive to the thrust settings selected and, in the absence of specific data, broad assumptions have had to be made. We recommend that Heathrow engage with the airlines to obtain suitable data to estimate take-off thrusts. Accurate fuel flow data should be available from the Flight Data Recorders. Research into this area may provide invaluable data that would improve the accuracy of the inventories. Alternatively, actual take-off weight statistics could be used to provide estimates likely take-off thrusts. Both these routes would require the co-operation of the airlines and non-disclosure agreements may be needed to allay their concerns over the commercial sensitivity of their data.

Considering the apparent reduction in the use of reduced engine taxiing on departure, the survey of its use on arrival should be updated to establish if it is similarly affected.

The methodology used to prepare these inventories is a significant enhancement on the methodology of the previous annual updates. As many of the datasets used are now routinely available, subsequent annual updates should continue to use or build on this approach.

6 References

[i] Peace H, Walker C T and Peirce M J (2015) Heathrow Airport 2013 Air Quality Assessment. Ricardo-AEA/R/3438.

[ii] Walker C T (2016) Heathrow Airport 2015 Emission Inventory, Ricardo- Energy & Environment/ED62191.

[iii] Walker C T (2017) Heathrow Airport 2016 Emission Inventory, Ricardo- Energy & Environment/ED10362.

[iv] Walker C T (2018) Heathrow Airport 2017 Emission Inventory, Ricardo Energy & Environment/ED11486

[v] https://www.heathrow.com/content/dam/heathrow/web/common/documents/company/about/expansion/Heathrow-Expansion-Consultation-June-2019.pdf

[vi] Heathrow Expansion PRELIMINARY ENVIRONMENTAL INFORMATION REPORT, Heathrow Airport Limited 2019

[vii] ICAO database Issue 28C, 20 July 2021 downloaded from https://www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank

[viii] https://www.icao.int/environmental-protection/Pages/CAEP11.aspx

[ix] ICAO Doc 9889, Airport Air Quality Manual, Second Edition, 2020

[x] https://www.emisia.com/utilities/copert/

[xi] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom

t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com