Department for Transport

Jet Zero: modelling framework

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Contents

1. Modelling development

Passenger and aircraft forecasting

Introduction

1.1 The analysis for the Jet Zero Consultation and the further technical consultation uses the Department's aviation model. The model framework was described in detail when a full set of forecasts was last published in 2017. The model, also used by the Climate Change Committee (CCC), has been updated in recent years in line with the department's policy of continuous improvement to its analytical models. Recent improvements have focused on bringing the model up to date to accurately represent UK aviation passenger demand, aircraft movements and emissions for 2019, the last normal year of aviation activity before the COVID-19 pandemic. The precision in forecasting aviation emissions throughout the period 2020-2050 has been further refined.

1.2 The structure of the modelling suite used for the current Jet Zero consultation is illustrated in Figure 1.[1]

1.3 The updated version has been rigorously tested and calibrated against data on passenger and aircraft movements and outturn emissions up to the point at which the COVID-19 pandemic disrupted UK aviation activity and therefore the updated model version has been deemed fit for use and now more suitable than its predecessor for use in assessing carbon emissions by UK aviation.

Uncertainty

1.4 Aviation demand forecasting over the rest of this decade is exceptionally difficult because of the impact of the COVID-19 pandemic on demand for UK passenger aviation. The department's forecasts are made by examining evidence and then mathematically modelling the long-term relationships between passenger aviation demand and its established economic drivers. The analysis of the long-term

[1] Note that for clarity Figure 1 only shows those elements of the modelling that have been active in the Jet Zero carbon abatements: downstream elements such as infrastructure economic appraisal and airport mode share modelling have been omitted.

relationship between aviation demand and its key drivers use continuous data series from the past 30 years. For the next few years, the relationship between aviation demand and these established drivers of demand may be different, and the strength and timing of full recovery remain uncertain. The confidence in any forecast out to 2030 will inevitably be lower than in previous forecasting.

1.5 The approach taken here is to forecast using the established relationships between demand and its drivers throughout the period 2016-2050. The most up to date forecasts on the economic drivers (GDP, trade, oil prices, taxes and fares) have been used, but these cannot fully explain the short-term disruption caused to aviation demand by the COVID-19 pandemic. This is reasonable in terms of looking at long-term strategies for abating carbon (CO2e) emissions,[2] given that the critical period when abatement measures begin to have real impact is likely to be 2030-2050. This approach presents a risk that the forecasting of underlying base emissions is an overestimate. But this is deemed an acceptable risk because when assessing potential strategies to reduce aviation CO2e emissions, it is preferable to take the precaution of starting from the most realistic high passenger demand growth baseline setting the greatest carbon abatement challenge.

[2] ‘CO_2e emissions’ are defined ‘CO_2 equivalent emissions and allow for other greenhouse gases emitted when jet-fuel is burnt including methane (CH_4) and nitrous oxide (N_2O) – these additional gases add only around 1% to the warming impact of CO_2. See also paragraphs 5.14-5.15.

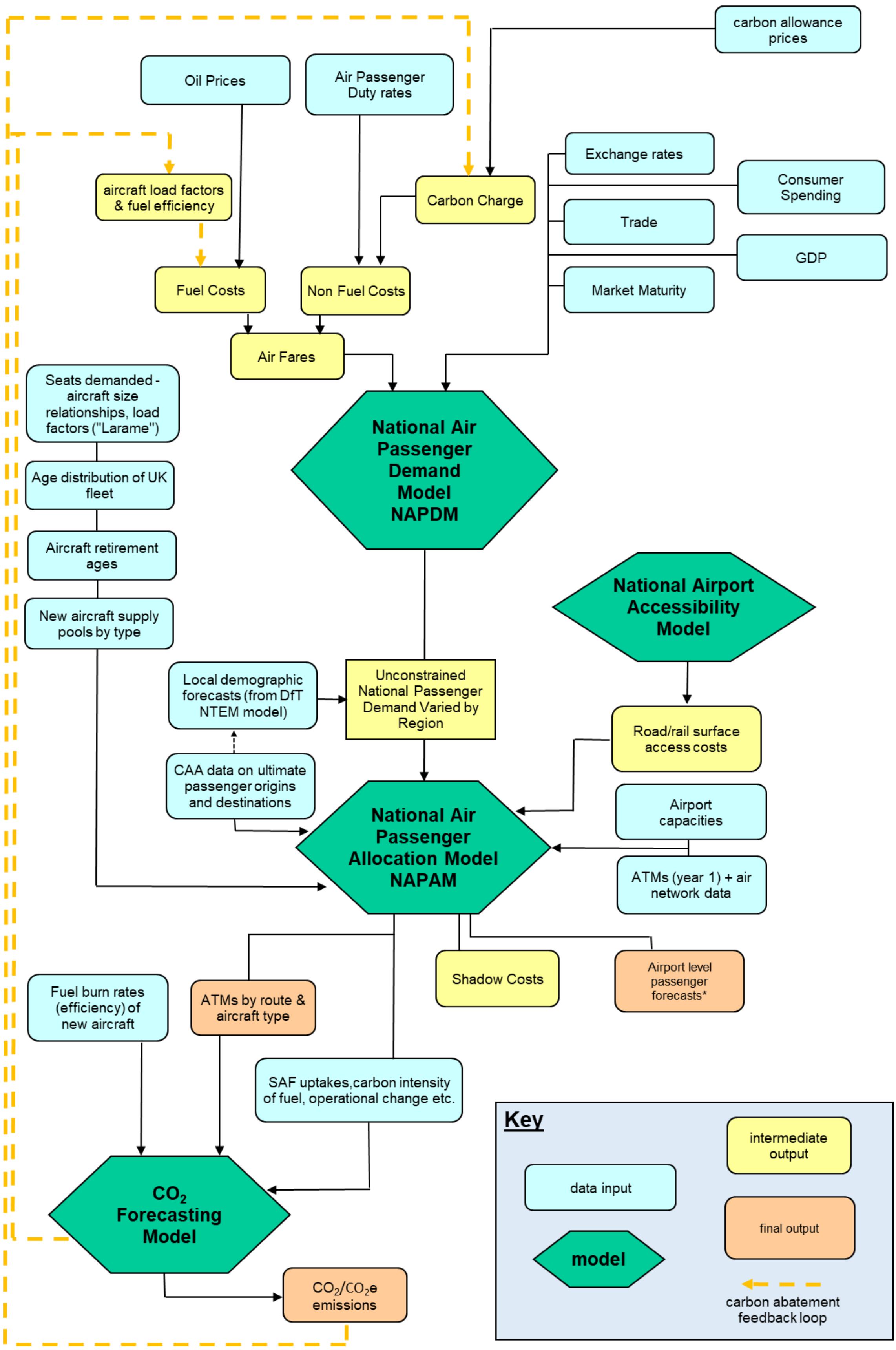

Figure 1 Aviation modelling suite used for Jet Zero

This report

1.6 This report accompanies and sets the scene for the companion document Jet Zero: further technical consultation and explains how the department have updated their aviation modelling suite since the last main forecasts were published in 2017. A significant range of updates have been made since then. This report summarises them and explains why the latest version of the model provides a robust base for forecasting aviation CO2e emissions. The report emphasises the change to a more modern and detailed world geography, new elasticities of demand, more precision in the aircraft forecasting and a robust pre-pandemic 2019 base year performance.

1.7 No passenger demand forecasts are presented in this document – but a wide range of possible UK aviation CO2e emissions pathways forecasts are presented in Jet Zero: further technical consultation. Although the airport allocation model is a necessary part of the carbon modelling process because of its aircraft forecasting, no detailed analysis of airport forecasts is presented as local competition between airports for international and domestic routes have little material effect on the emissions forecasts at a national level.

- **Chapter 2** describes the changes made to the National Air Passenger Demand Model (NAPDM). It explains how these impact on the national forecasts with reference to the new elasticities, updating of economic driver forecasts and the treatment of carbon pricing.
- **Chapter 3** introduces recent changes in the National Air Passenger Allocation Model (NAPAM). These include a more precise geography, a new validated base year of 2019, updated 'making best use' capacities and
- In **Chapter 4** there is a description of how the Fleet Mix Model (FMM), previously exogenous, now operates more precisely at the route level inside NAPAM at the point at which ATMs (air transport movements) are calculated.
- **Chapter 5** updates the CO2 model[3] downstream of NAPAM, essentially unchanged from the last model version, but updated to and validated against 2019 CO2e emissions returns.

[3] Note that the department's 'CO_2 Model' can output results in units of CO_2 or CO_2e. Throughout this analysis CO_2e is the unit of emissions, 'CO_2' is only used when referring to the modelling tool itself.

2. National air passenger demand forecasts (NAPDM)

Introduction

2.1 The National Air Passenger Demand Model (NAPDM) is the starting point of the path that leads to the aircraft (ATM) and CO2e emissions forecasts in the department's aviation modelling suite. It produces national level estimates of the demand for passenger trips unconstrained by airport capacity. These forecasts are passed downstream to other models in the modelling suite which allocate these trips into passengers at airports, aircraft movements and CO2e emissions.

2.2 NAPDM consists of econometric models to estimate demand elasticities for passenger markets for different journey purposes and regions of the world. The markets are defined by:

- whether a passenger has an international or domestic destination
- the global region an international passenger is travelling to or from
- whether the passenger is a UK or foreign resident
- the journey purpose (leisure or business)
- whether the passenger is coming to the UK or just passing through a UK airport to connect between international flights

2.3 The key drivers in the econometric models are incomes and associated economic activity, and air fares with the models modified over time to take account of market maturity assumptions.

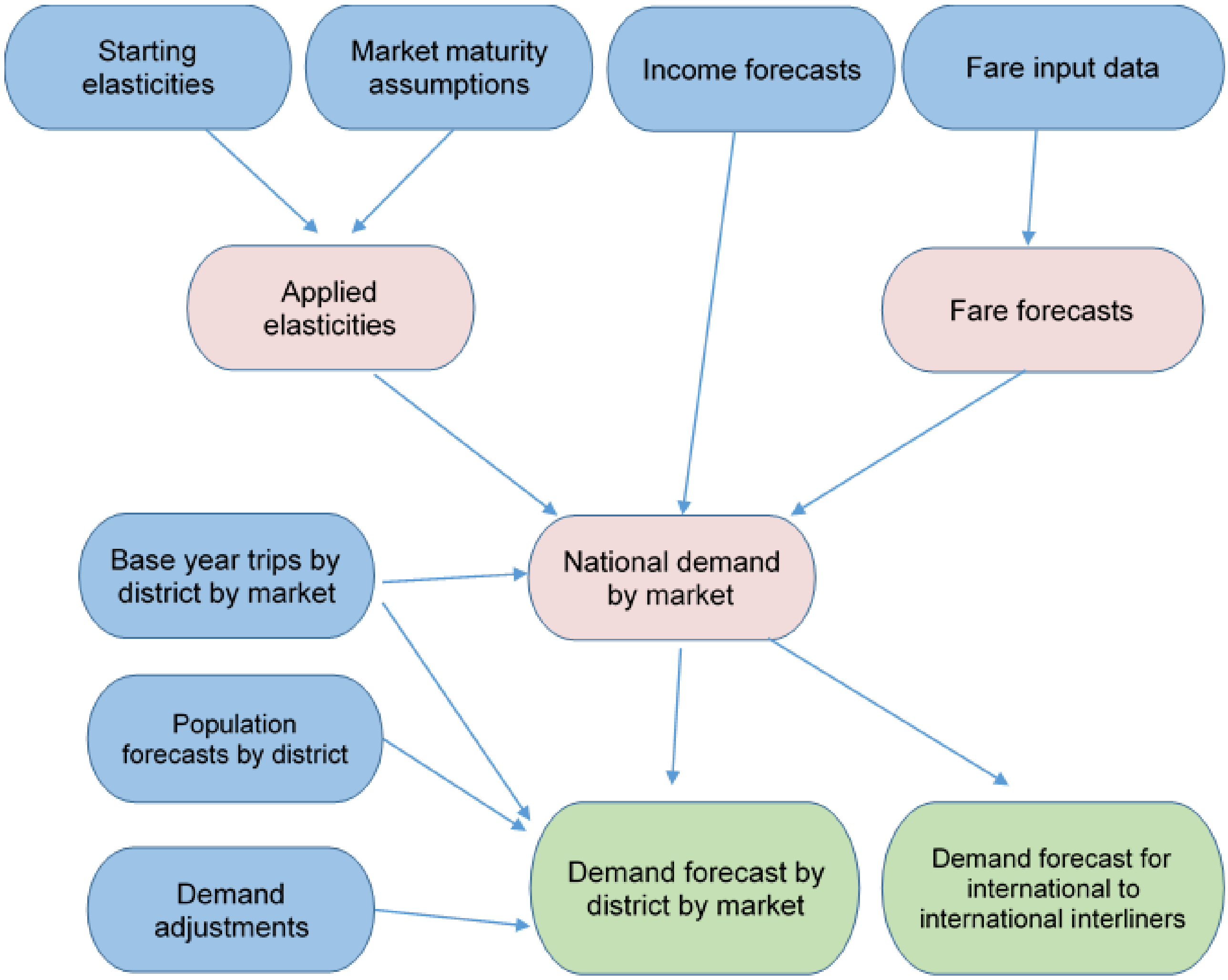

Figure 2 NAPDM model structure

2.4 The NAPDM fare forecasts module plays an essential part of the emissions forecasting and assessment of carbon abatement scenarios.

2.5 The fares module breaks future fares down by modelling market into key variable elements including:

- fuels costs per passenger allowing for the impact of changes in the expected passenger load factors of the regional aircraft fleets; and forecast changes in the fuel efficiency of the future aircraft fleet
- carbon prices
- UK aviation taxes (Air Passenger Duty (APD))
- all other non-fuel and non-tax related airline costs

2.6 In most model applications the model process cascades from NAPDM and its macro-economic inputs through the airport and aircraft forecasting down to the CO2 emissions output model. However, it is recognised that future changes to input carbon prices could significantly affect the fuel efficiency of the aircraft fleet, uptake of alternative fuels and aircraft passenger loadings. As such changes can have an impact on fares, and therefore demand, there is an option to use an iterative feedback loop between the CO2 emissions model and NAPDM demand forecasts.[4] This model feedback relationship, illustrated in Figure 1, has been used in Jet Zero.

2.7 A full account of the NAPDM forecasting principles is in the department's 2017 aviation forecasts document and much of this remains valid. However since 2017 there have been significant updates and improvements to NAPDM.

- The domestic and international econometric models have been re-estimated and new long-run income / economic activity and price elasticities of demand have been derived using time series data covering the period 1986-2017.

- Although there are still 16 international markets (2 passenger residency * 2 journey purposes * 4 world regions), the international regions (agglomerations of countries) have been redefined to provide both better fitted econometric models and more evenly sized passenger markets. As explained below, it better represents the changing pace and character of regional world economic development in recent years.

- NAPDM now outputs unconstrained demand of national passenger trips rather than estimates of national terminal passengers (avoiding the need to make assumptions about patterns of transfer – beyond the scope of NAPDM).

- Instead of applying just one carbon price series across all regions, as in the previous version, the NAPDM fare model can now apply a different carbon price series to different markets. This can better reflect the impacts of different carbon pricing mechanisms on demand and emissions in relevant world regions. Specifically, assumptions about UK ETS carbon prices are applied to the new Southern Europe (SE) and Rest of Europe (RoE) forecasting regions, while assumptions about ICAO CORSIA eligible emission unit prices are applicable to OECD and Rest of World (RoW) regions.

- All the main economic inputs driving growth have been updated to the most recent available OBR, OECD, IMF forecasts, and all other external model input reviewed.

2.8 As before, NAPDM continues to model the domestic and international to international transfer market separately to the 16 international markets. Domestic passengers flying within the UK are split into business and leisure (2 markets), while international to international transfers, with no ground origin or destination in the UK, are not split by journey purpose. In addition, all the UK based demand forecasts are allocated to a regional level based on ONS population forecasts, as described at the end of this Chapter.

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[4] This outer iterative forecasting technique was first used and rigorously tested in by the Airports Commission to produce demand forecasts fitted to carbon targets – see Strategic fit: updated forecasts (publishing.service.gov.uk) especially chapter 4. Note CO_2e targeted forecasts are not used in the Jet Zero assessments, but the feedback mechanisms are. Jet zero feedbacks are used to impact the fuel efficiency and load factor inputs to the NAPDM fares per passenger model rather than the input carbon price which is calculated off-model.

Geographical definition

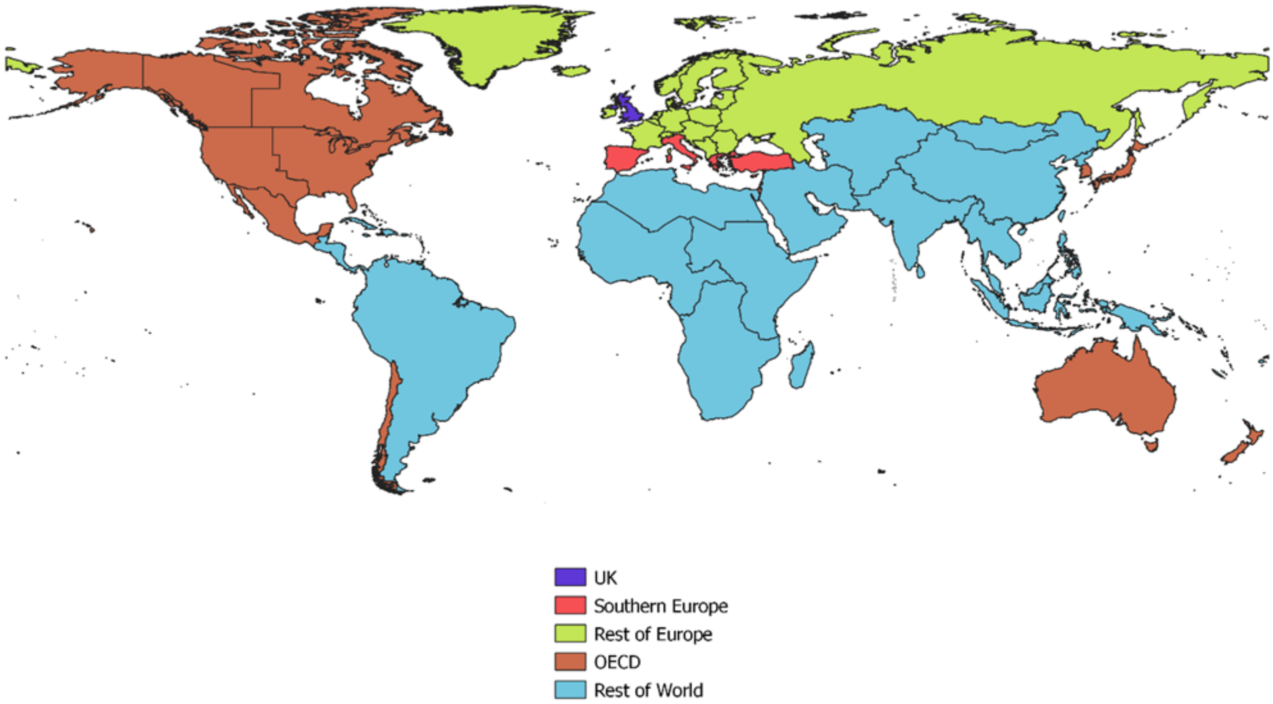

Figure 3 Updated NAPDM forecasting regions

2.9 The 2017 forecasts version of NAPDM used in the consultation had four global regions: Western Europe (which in practice encompassed all short-haul, being all of Europe including Russia), OECD (long-haul members), Newly Industrialised Countries and Less Developed Countries. There were two problems with this old grouping which became more prominent over time.

1. The region sizes were not well balanced, with the “Western Europe” region being responsible for about 80% of all international traffic.

2. The old distinction between the ‘Newly Industrialised Countries’ and the ‘Less Developed Countries’ regions had become problematic with some countries arguably moving between categories during the relevant period.

2.10 Resolving these issues also meant that more robust econometric models could be calibrated out of the newly extended 1986-2017 time series data. The current international NAPDM model is now disaggregated into four revised global regions:

- Southern Europe (SE)
- Rest of Europe (RoE)
- Other OECD countries (OECD)
- Rest of the World (RoW).

2.11 The change in the short-haul/Western European market is significant. It is now split into two with the largest market, Southern Europe, representing slightly under 50% of total European trips. The long-haul Less Developed and Newly Industrialised categories have effectively been merged as long-haul Rest of the World while the other long-haul region, OECD, is essentially unchanged from the previous version of NAPDM.

2.12 The European market has been split according to market type. When travelling for leisure, people often travel to Southern Europe for 'sun and sand' holidays, and the Rest of Europe for a variety of business, tourist and cultural attractions. It is recognised that this distinction is often not clear-cut. For example, France, a major destination, could be included in either category but was placed in the Rest of Europe market.

Demand elasticities

2.13 Since 2017, the econometric models have been re-estimated to provide updated demand elasticities. These reflect both the extension of the time series of aviation, and a review of current best practice in academic econometric and mathematic modelling. The modelling has gone through both internal peer review and external academic review processes.[5] The updates include:

- The unit of measure of demand for elasticities in NAPDM has changed from terminal passengers to trips. The difference between the two relates to the way passengers are counted in national aviation forecasting: a passenger who transfers at a UK airport will be counted as two to three terminal passengers for each airport arrival and departure on a one-way trip.[6] The need to transfer at an airport can only be properly represented over time by a passenger to airport allocation model (i.e. NAPAM), so at this point in the modelling it is preferable to work with passenger trips.

- As described above, the grouping of countries into international regional markets has changed. The transition of the former Western Europe, OECD, Newly Industrialised Countries and Less Developed Countries regions into the four new global trip forecasting regions of Southern Europe (SE), Rest of Europe (RoE), Rest of OECD (OECD) and Rest of the World (RoW), necessitates new econometric models and elasticities.

- Input data on aviation demand and its economic drivers are updated and extended from a final year of 2008 to 2017. The data include principally annual aviation passenger numbers by journey purpose, income measures (e.g. GDP, import and export), and air fares.

- The current models introduce structural breaks, where applicable, into the series and derive demand elasticities separately before and after the structural breaks. Although

[5] The external academic review stated that the current state-of-the-art practice has been followed, and it concluded that no better elasticity estimates could have been obtained within the current form of modelling and data resource availability.

[6] For example, on an outbound one-way trip a UK originating passenger transferring at a UK hub will count one passenger movement (a departure) at the local departure airport and two passenger movements (an arrival and departure) at the hub airport when they transfer. A non-UK originating transfer will count as two passenger movements: an arrival and departure at the UK hub airport.

tests for structural breaks were undertaken when the previous NAPDM models were estimated, no robust evidence was then found, probably because of the shorter time series.

- The explanatory variables (economic drivers) have been found to be the same as in the previous version of NAPDM. But while the previous models included the sterling exchange rate to US dollar as a driver in only the foreign leisure to OECD market, exchange rates have now been found to be significant drivers in in more markets.[7]

2.14 These developments mean that the demand elasticities with respect to income (yed) and price (ped) are changed. The headline previous and current demand elasticities in broad passenger groupings are summarised below. The full set of market elasticities by purpose (‘U’=UK resident, ‘F’=foreign resident, ‘B’ =business passenger, ‘L’ = Leisure passenger by region (D=Domestic, SE, RoE, OECD, RoW) are tabulated in Annex A.

[7] More information is in supporting document Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model, Department for Transport, March 2022. Also note that in old and new versions of NAPDM, although exchange rates are a significant explanatory variable of historic air demand, exchange rates are not varied for the purposes of forecasting future demand.

	Previous NAPDM elasticities		Current NAPDM elasticities	
	income	price	income	price
Passenger type	yed	ped	yed	ped
All business passengers	1.0	-0.2	0.9	-0.2
All leisure passengers	1.2	-0.6	1.3	-1.1
Southern Europe	1.2	-0.7	1.2	-1.0
Rest of Europe	1.1	-0.6	1.2	-0.9
OECD	0.9	-0.3	1.1	-0.9
Rest of World	1.1	-0.4	1.8	-0.9
All domestic passengers	1.2	-0.5	1.1	-0.6
All UK residents	1.2	-0.6	1.1	-0.9
All foreign residents	0.9	-0.5	1.6	-0.9

yed: income elasticity of demand
ped: price elasticity of demand

Where elasticities do not relate to a specific market, they have been weighted

Previous NAPDM regional elasticities have been re-weighted by country to provide equivalence with the current geographic definitions

2.15 A full technical account of the updating of NAPDM's econometric models is in the associated document: Econometric Models to Estimate Demand Elasticities for the National Air Passenger Demand Model, Department for Transport, March 2022.

Input assumptions and sources

2.16 Since the 2017 forecasts were published, key model inputs have either changed sources or been replaced by more recent publications from the same source. The external data sources were brought up to date at the start of this current phase of model development in autumn 2021. Figure 4 below summarises the sources used to project the key drivers of demand in the current model.

2.17 Input GDP and other income related forecasts include the projected wider impacts of the COVID-19 pandemic and recovery of the UK and world economies. In the main forecasts this is the only direct inclusion of the pandemic effects.[8] It is therefore assumed that the long-term relationship between demand and key drivers estimated from historic data is unaffected by the pandemic.

Model Input	Period	Source
UK GDP, Growth Rates	2015-2020	ONS, August 2021
	2021-2080	OBR, October 2021
Consumption Expenditure, Growth Rates	2015-2080	OBR, various years
Foreign GDP Growth Rates	2015-2026	IMF, April 2021
	2027-2060	OECD, July 2018
	2061-2080	Held constant by assumption
GDP Deflator Growth Rate	2015-2020	ONS, August 2021
	2015-2026	OBR, October 2021
	2027-2080	Held at 0% by assumption
ETS Carbon Prices	2015-2080	DfT carbon price series for aviation modelling[9]
CORSIA Carbon Prices	2021-2080	DfT carbon price series for aviation modelling
Oil Prices	2015-2080	BEIS, February 2020
Exchange Rate	2015	ONS, May 2017
	2016	BEIS, 2016
	2017-2026	OBR, various years
	2027-2080	Held constant by assumption
APD	2015-2023	HMRC, April 2021; Autumn Budget 2021
	2024-2080	Held constant by assumption
Load Factors	2015-2050	NAPAM, November 2021
	2051-2080	Held constant by assumption
Fuel Efficiency	2015-2050	NAPAM, November 2021
	2051-2080	Held constant by assumption
Trips by District	2020-2080	DfT
Population by District, Growth Rates	2015-2080	DfT NTEM v7.2

Figure 4 NAPDM current input demand driver data sources

Carbon price and fare modelling

2.18 When NAPDM applies the various price elasticities to changes in fare by forecasting market (see Annex A), it uses a model of future fares for each market. The components and sources of the NAPDM fares model are detailed in the footnote to Annex A.

2.19 In the context of Jet Zero abatement scenarios, carbon prices are a particularly important component in the NAPDM fare model. Carbon prices are a cost element to airlines that they are expected to pass on to consumers through air fares. The higher

[8] Except, as discussed in Chapter 4, the accelerated removal of some older less fuel efficiency aircraft types from the UK fleet in the ATM modelling, to reflect what had been an observed response to lower demand by some airlines.

[9] See Annex B of Jet Zero: Further Technical Consultation for details.

carbon prices, the higher the air fares, and this in turn drives down the total national aviation demand.

2.20 The previous version of the NAPDM model had applied one carbon price series across all routes. However, since the departure of the UK from the EU ETS carbon trading scheme, flights within the UK and from the UK to the EEA are treated as part of the new UK ETS scheme, while the remaining, mainly long-haul, international flights are covered by ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme.

2.21 The NAPDM fares model has therefore been extended to apply different carbon price series to different markets. UK ETS Carbon prices are applied to the Southern Europe (SE) and Rest of Europe (RoE) regions while CORSIA prices are applied to OECD and Rest of World (RoW). Further detail on the carbon price assumptions used in the modelling is given in Jet Zero: further technical consultation.

Air Passenger Duty

2.22 In October 2021 the Government announced a halving of Air Passenger Duty (APD) on domestic flights to £6.50 (nominal) and a new 'extra-long-haul' band C for flights over 5,500 miles. In nominal values Band C is Band B (2,000-5,500 miles) +£4 for an economy ticket. These changes are due to be introduced in 2023 and have been included in the NAPDM forecasting from then.

2.23 APD rates used in NAPDM are based on HMRC figures set out in April 2021 and rates and regime later amended in the Budget of 2021. The rate in each geographic region in the forecast model is aligned with APD geographic bands using CAA passenger survey data and is a weighted average across APD rates for reduced and standard classes. In addition, an adjustment has been made to reflect that those aged under 16 are now exempt. The rates are assumed to be held constant in real terms for the rest of the modelling period and are only applied when departing from a UK airport. The table below sets out the average rates used in the forecasts converted from the APD band areas to the NAPDM forecasting regions in 2015 prices.

NAPDM region	2015 APD rate, £	2023 APD rate, £
Domestic end-end	26	11
Southern Europe	13	11
Rest of Europe	13	11
OECD	75	91
Rest of World	63	86

APD is paid when departing a UK airport, and aviation trips entirely within the UK involve doing so twice. Prior to 2023, the domestic end-end rate is about double the Southern Europe and Rest of Europe rate because of this.

Fuel efficiency and load factor inputs

2.24 As illustrated in the aviation modelling suite structure in Figure 1, there are optional outer iterative loops between the connecting outputs from the CO2 Model and fare inputs of NAPDM.

2.25 Load factors and the fuel efficiency of the aircraft fleet both can have some impact on the series of fares, given the same carbon prices. The fuel efficiency feedback loop has been used in the context of the Jet Zero illustrative scenarios reported in the Jet Zero: further technical consultation.[10] Higher load factors result in lower fares overall as the fuel, carbon charge and non-fuel cost air fare components are spread across more passengers. Greater output indices of fleet fuel efficiency by forecasting region are used to adjust the fuel cost per flight, so increased fuel efficiency results in some reduction of average air fares in the model feedback loop. The indexed fuel efficiencies by NAPDM region are shown in Figure 5 below.

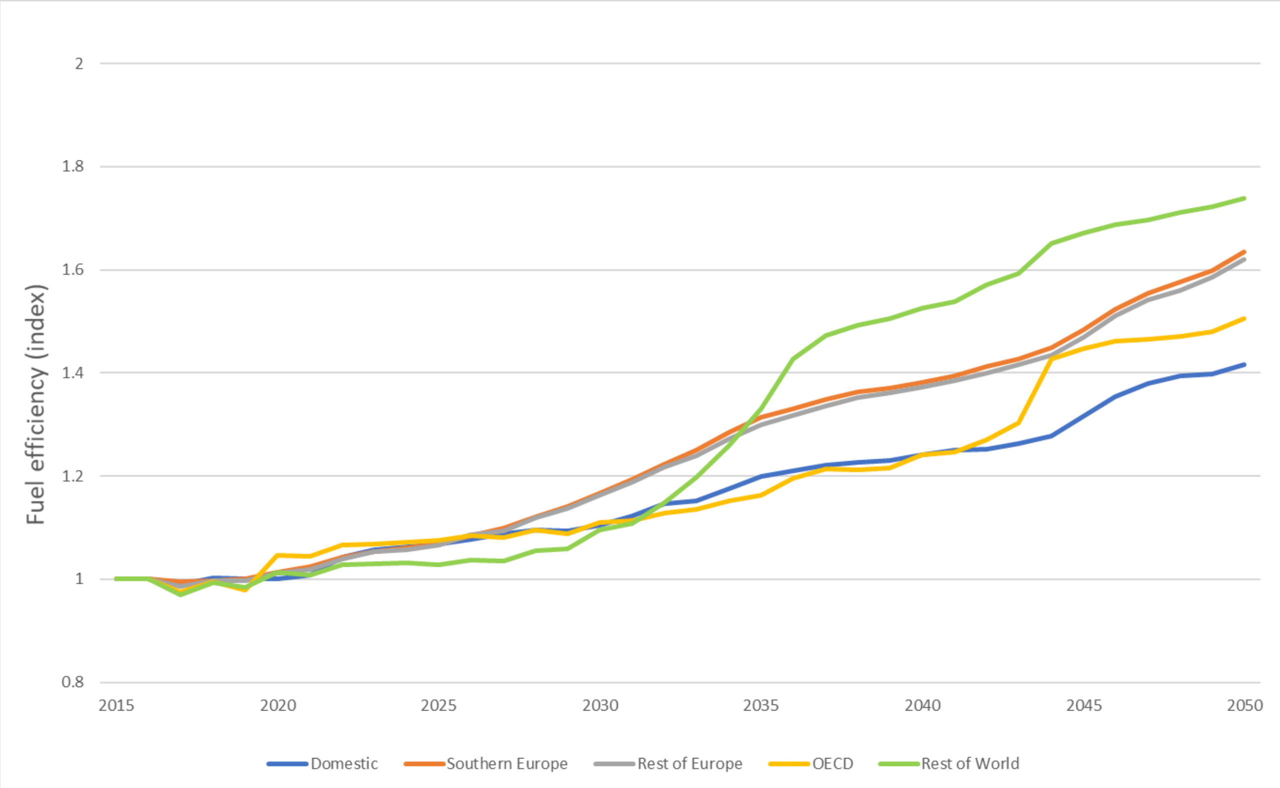

Figure 5 Baseline indices of fuel efficiency by NAPDM forecasting region

Overall change in modelled fares

2.26 Figure 6 below provides an overview of the modelling of average total fares split by component and shows how the carbon component of air fares progressively increases through the modelled period. The graph in Figure 6 shows an

[10] Fuel efficiency is measured as seat-kms/tonne of fuel, to eliminate the impact of the passenger load factor from the rate of fuel efficiency.

amalgamated fare for all international passenger forecasting markets weighted by total trips.[11]

2.27 In all years, the single largest fare element shown in Figure 6 is 'other costs'. These costs are not separately modelled but include staff salaries, equipment maintenance, depreciation or lease, insurance, navigational and airport passenger handling fees, landing and departure fees and parking charges, and marketing, promotion and other general administration costs.

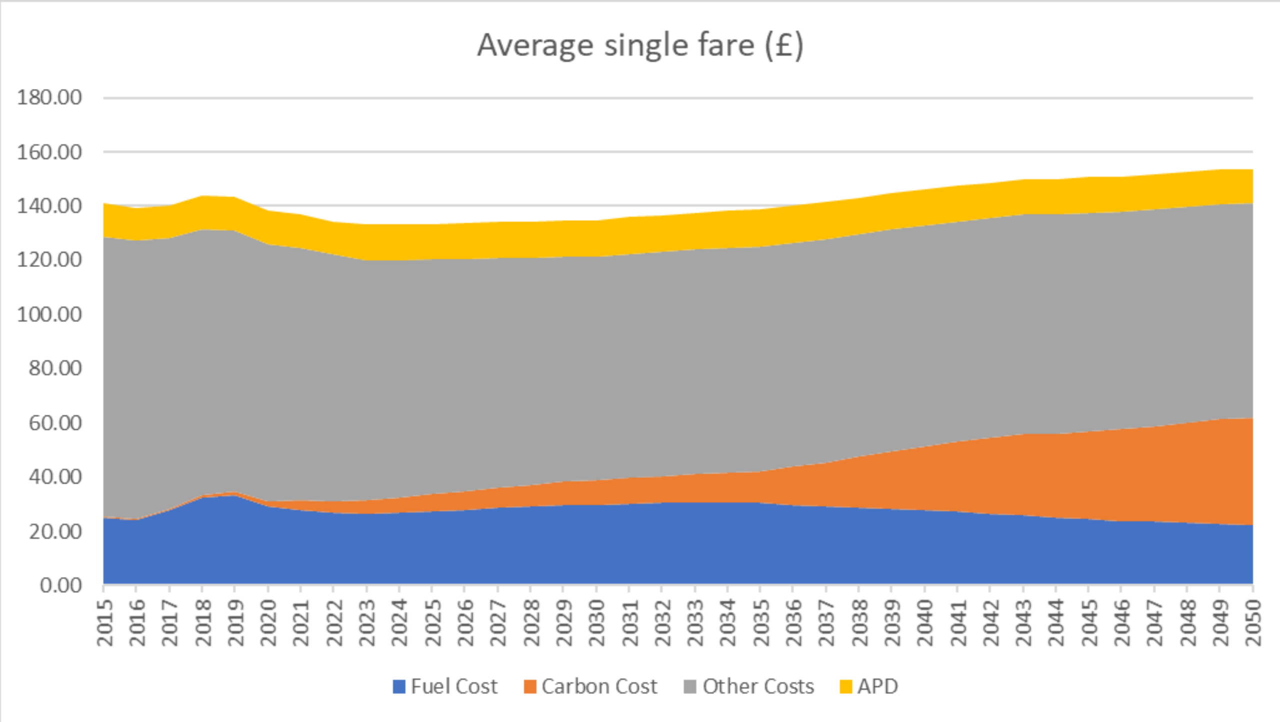

Figure 6 Projected composition of future air fares weighted by trips, central demand

Distribution of national demand around the UK regions

2.28 NAPDM has a function to manage the disaggregation of the growth in demand to the more local district level needed to allocate forecast national demand to airports in the passenger to airport allocation model NAPAM while controlling to the forecast national trip totals. NAPDM determines how the local distribution within the national trip forecast may change over time. The 2017 forecasts document reported how, after a series of statistical tests, changes in the local district composition of demand were driven solely by projected local population changes.[12] Districts with faster forecast population growth received a higher share of each market's forecast demand growth.

2.29 This approach has been reviewed since the 2017 forecasts. Some stakeholders, such as airport operators in the north of England, had raised concerns that this

[11] In practice in NAPDM the fares are separately calculated for each regional market and journey purpose.
[12] The population projections for the period 2016-2051 for mainland UK were taken from the department's Tempro 7.2 trip end model, which uses ONS data to forecast population growth by district for Great Britain. with ONS principal population projections for Northern and the Republic of Ireland's Central Statistical Office for the rest of the island of Ireland.

approach disproportionately allocated demand to London and the south east, at the expense of northern regions.[13]

2.30 Further statistical regressions have been used to re-test population growth against other potential economic variables which could be possible drivers of regional variations in propensity to fly. Again, population growth was consistently found to be a significant driver as a single explanatory variable. Similar regressions on other economic indicators – Gross Value Added local income (GVA) and Gross Domestic Household Income (GDHI), GVA per head, and GDHI per head – also demonstrated their significance as sole explanatory variables. But GVA and GDHI were also found to be significantly correlated with population, and this justified retaining the use of independent (ONS) forecasts of population growth as the sole driver of regional variation in propensity to fly.

2.31 A second stage in the review was to test the forecast accuracy of the 2017 forecasts methodology over various sample periods which were then compared to historical demand data. The forecasting accuracy of the methodology was tested by estimating the correlation between actual and forecast demand over given sample periods. A high correlation was found at the local level between historical demand and the demand forecast using the population growth based method.[14]

2.32 Doubtless local factors do play a role, often short term, in changing the propensity to fly from regions and local airports. But such factors are hazardous to predict over the longer term. Overall, the review clearly found that the alternative methodologies considered did not consistently outperform the methodology used in the department's 2017 forecasts. The 2017 methodology demonstrated a good forecast performance while being both simple and based on transparent and widely available ONS projections. Therefore, the population based growth methodology is retained for the current NAPDM baseline distribution of future demand around the regions.[15]

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[13] However, it should be noted that after a brief period, 2016-2017, when regional throughputs outgrew the London and SE airports, since 2017 there has been a return to the long-term pattern of London & SE airports displaying stronger growth rates, even in the COVID-19 affected year of 2020.

[14] A further variation on the population growth-based methodology was also tested. This method applied a population elasticity based on estimation or calibration to demand growth. The results showed that the local demand forecast based on alternative elasticities estimated or calibrated were over-sensitive to sample selection. The reliability of this alternative was also undermined by poor out-of-sample forecast performance of the sample alternatives.

[15] Regional variations are controlled to the overall national trip growth forecast produced by the econometric models, so, although NAPDM incorporates a regional growth scenario override function which can redistribute the overall growth around the regions, there is little reason in applying local overrides in the context of Jet Zero forecasting as any impact on national CO_2e emissions totals would be minimal.

3. National Air Passenger Allocation Model (NAPAM)

3.1 As set out in the 2017 forecasts document, the National Air Passenger Allocation Model (NAPAM) takes national forecasts of the demand for air passenger trips to and from and within the UK from the national NAPDM forecast. Passengers are allocated around the main airports throughout the UK and four competing overseas hubs. It forecasts how passengers might choose airports in reaction to their relative estimated attractiveness now and in the future. This choice takes account of current and future limits to and pressures on airport capacity, accessibility and levels of air services.

3.2 As part of this process, it also translates passenger demand for different routes into ATMs (air transport movements), i.e. the demand for aircraft flights. Specific current and forecast aircraft types on each route are forecast for use downstream in the CO2e emissions modelling.

3.3 A comprehensive range of software improvements and updating of inputs in the current version of NAPAM have allowed

- greater geographic detail and compatibility with NAPDM forecasting regions
- good quality model validation of performance against 2019 actuals on passengers, aircraft and emissions at UK airports
- updating of the airport capacity assumptions to be used specifically for aviation emissions modelling in line with recent airport planning applications or specific proposals published by UK airports since 2018
- improved model convergence through tighter fitting of demand to the annual runway capacity of individual airports
- better representation of recent trends in aircraft passenger load factors
- greater precision of present and future route-level aircraft type forecasting by incorporation of the Fleet Mix Model directly into the NAPAM.

3.4 Significant modernisation of the NAPAM program software, faster run times and a greater range and granularity of its outputs have further facilitated rigorous model checking, a general upgrade in model performance and an improved range of outputs.

3.5 Some other pipeline model improvements less directly connected to the emissions modelling, or which have been less thoroughly tested or supported by robust input assumptions, have been withheld to avoid unnecessary inconsistency with the previous CO2 forecasts.[16]

Geographical definition

3.6 The UK mainland geography of 455 district-based ground origins described in the 2017 forecasts document remains unchanged.[17]

3.7 The modelling treatment of Northern Ireland has been upgraded to incorporate 37 new zones on the island of Ireland. This means that the two Belfast airports will no longer be modelling "add-ins" but are now modelled in the same way as the mainland UK airports. Locally this provides more responsive and consistent passenger allocation and ATM modelling.

3.8 The international geographical definition used in the 2017 and earlier forecasts has been substantially revised and modernised. The previous 48 modelled international destination zones of (27 route groups and 21 individual European airports) had not been changed since the model was first developed. They have now been replaced with the 67 zones illustrated below in Figure 7 and listed Annex B. The reasons for making changes were:

Modernisation: the previous system was becoming outdated.

- The previous separately modelled 21 European airports represented the busiest destinations in the 1990s. That selection proved durable, but some relatively minor updates (Budapest, Malaga, Alicante, Berlin in, Nice out) reflect significant changes in demand in the past 20 years.

- Dubai as a major international transfer point for UK passengers had previously been represented as part of a Middle East zone group, its recent development requires modelling as an individual airport.

[16] Such ongoing developments, and reasons for exclusion, include: extending the model run horizon from 2050 to 2080 because of an absence of post 2050 aircraft fleet assumptions; new passenger to airport choice model coefficients because of shortage of time to test and check airport allocation against actuals; removal of the scheduled, charter, low cost airline types from the airport choice modelling because of delay in adopting new model choice coefficients; and, modelling updated airport surface accessibility costs as these have been affected by significant recent announcements of changes on future rail schemes but also have relatively little impact on total aviation emissions, which are driven primarily by international travel.

[17] Using 1991 census boundaries for greater granularity.

- Major political, economic and demographic changes in world geography since original model development are reflected e.g. the growth of China and the accession of eastern European countries to the EU.

Boundary consistency.

- The new zones can be aggregated precisely to align with boundaries such as membership of the EU, the EU ETS, the OECD etc.

- greater internal consistency within the department's aviation modelling suite: the new NAPAM zoning is now compatible with new NAPDM and short-haul and long-haul definitions (see Annex B).

Improved precision in the passenger allocation ATM and CO2e modelling

- Because of their diversity, several of the larger previous generation of zone groups had become more difficult to model in terms of validating model forecasts against current patterns of observed demand

- defining the mix of aircraft types going to specific destinations becomes more precise

- distances flown become more precise

- precision of CO2e emissions modelling benefits from all the above.

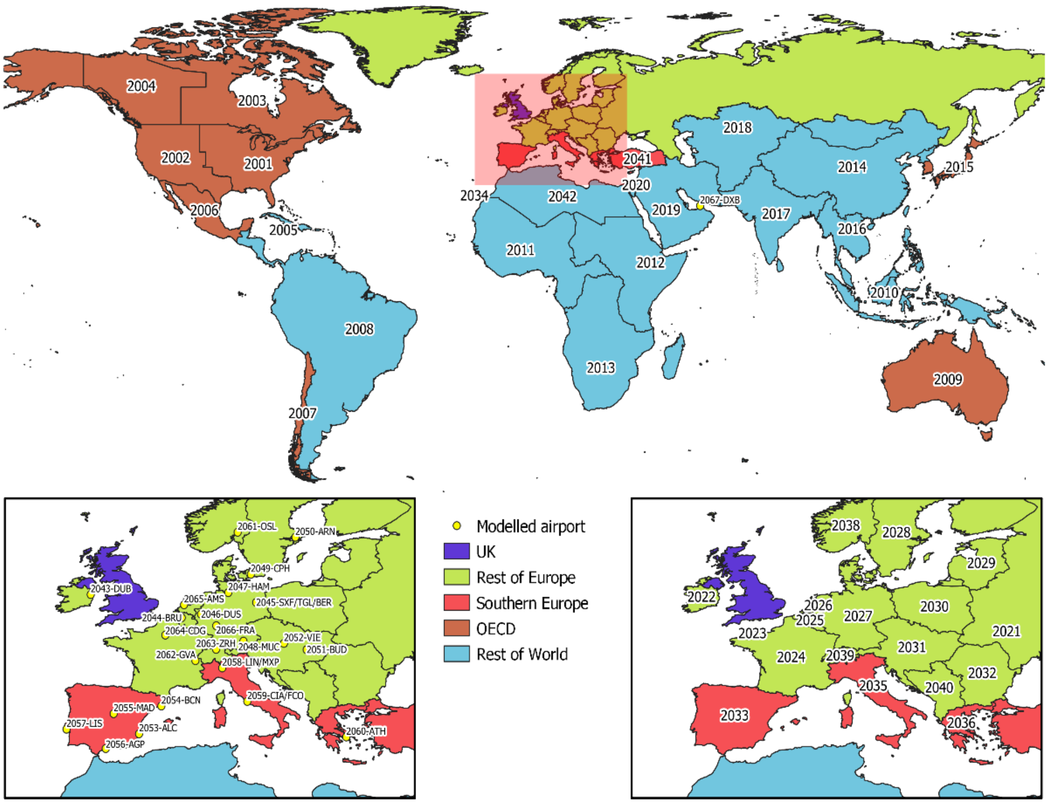

Figure 7 New NAPAM 67 international zone system

Airports modelled in NAPAM

3.9 NAPAM continues to model all the busier UK airports which had some regular international commercial passenger air services operating in 2019. As described in the next section, the airports are modelled as constrained by their assumed annual runway capacities or, in some cases, by terminal capacities. Forecasts are still made at the "route" level where a route here is defined as one of the modelled UK airports to one of the 67 international modelled zones and domestically from one of the UK modelled airports to either another UK modelled airport or a smaller unmodelled UK airport. International routes can also include flying via one of the major overseas modelled hubs: Amsterdam Schiphol, Paris Charles de Gaulle, Frankfurt or Dubai.

3.10 The only changes to NAPAM's set of UK modelled airports made since the 2017 forecasts is the removal of Blackpool and Coventry airports where commercial international services have been absent for several years. The representation of Belfast International and Belfast City airports has been upgraded by modelling the surface ground origins of their passengers and their airport access in the same manner as the mainland UK airports. The current list of UK airports modelled in NAPAM is given in Annex C.

3.11 The modelling for the Jet Zero Consultation and the further technical consultation focuses on forecasting emissions to illustrate the different pathways reducing international and domestic UK aviation emissions at the national level. There is therefore less focus on levels of activity at individual airports. But airport constraints are still expected in the future and capacity constrained airport modelling continues to underlie the emissions modelling.

Model performance: passengers and ATMs 2019

3.12 NAPAM modelling starts in the year 2016 with a base origin and destination pattern of demand for that year and applies the NAPDM growth factors for each market and forecasts each year out to 2050. The year when modelled performance is validated against independent statistics has been advanced to 2019, four years into the modelling period. Model validation checks:

- allocation of passengers to airports
- conversion of passenger demand to aircraft (ATM) demand at each airport
- representation of passenger loadings on aircraft at each airport.[18]

3.13 The model has therefore been thoroughly quality checked on its performance against observed aviation activity immediately before the disruption to the industry caused by the COVID-19 pandemic, and it performs well.

3.14 Annex E summarises performance of the model's passenger to airport allocations (including competing major overseas hubs) against statistical outturns ('actuals')

[18] Passenger loads, calculated at the NAPAM route level, are a combination of model performance in terms of representing reasonably accurately both aircraft size and load factors.

provided by the CAA for 2019.[19] There is a good match between predicted passenger numbers and the actuals at all the major passenger airports.

3.15 Annex F provides the model performance in converting passenger demand to ATMs against statistical outturns ('actuals') provided by the CAA for 2019 and in making a good representation of average passenger aircraft loadings at each modelled airport. Both are important outputs for accurately assessing CO2e emissions abatement strategies. Both provide a good match between the actuals and modelled.

UK airport capacities

3.16 These basic principles apply to airport capacity modelling used in the department's updated aviation modelling suite:

- all airports must be given an assumed annual runway capacity (an upper bound on the number of aircraft movements that can be accommodated on a runway); in some cases, runway capacity inputs may have been set by local planning consents or planning proposals.
- terminal (passenger) capacity constraints are now only used where there is a current planning restriction in place, or a decision on a current planning application is expected to result in a restriction on passenger numbers.[20]
- in most cases where no terminal capacity is available, effective passenger capacity assumptions in any year is calculated in the model as passenger aircraft movements multiplied by the average modelled aircraft load for that airport in that year.

3.17 The capacity assumptions required by the model do not pre-judge the outcome of any future planning applications, including decisions taken by Ministers. The capacity assumptions do not represent any proposal for limits on future capacity growth at specific airports, nor do they indicate maximum appropriate levels of capacity growth at specific airports for the purpose of planning decision-making. However, specific assumptions must be made on several inputs, including about the future runway capacity of the main airports in the UK, for NAPAM to operate. In line with a precautionary approach to the level of future carbon emissions, and to reflect the uncertainty around future developments in this area, we have assumed capacities that are consistent with current planning applications, including proposals on which airports have consulted the public (e.g., statutory pre-application consultation). Increasing capacity limits in this way allows the analysis to focus on testing the potential of abatement technologies to meet the challenge of net zero, without capacity constraints imposing an extra demand restriction or simply causing emissions to be exported to competing overseas airports.

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[19] CAA only provide statistics for UK airports – see DfT Transport Statistics UK for overseas hubs - Aviation (TSGB02) - GOV.UK (www.gov.uk).

[20] The airports with a consent, application or a planning consultation that have been given a specific planning passenger capacity are London City (11mppa), Luton (32mppa), Stansted (43mppa), Bristol (12mppa), Southampton (3mppa) and Leeds-Bradford (7mppa). All these airports will also be given an assumed annual runway capacity and the airport activity will be limited to whichever of the two capacities ceilings is reached first.

3.18 In June 2018, the government set out its policy support for airports to make best use of their existing runways in Beyond the Horizon: The future of UK aviation: making best use of existing runways ("MBU") and a new runway at Heathrow Airport in the Airports National Policy Statement: new runway capacity and infrastructure at airports in the South East of England (ANPS), subject to related economic and environmental considerations. In common with the Jet Zero Consultation the capacity assumptions in our modelling reflect and are aligned with these policies. The assumptions for a small number of airports have been updated only where better evidence has become available.[21] These include factoring in changes to the assumed delivery timeframe of a third runway at Heathrow, as a result of expansion activity pausing during COVID-19. Heathrow Airport Limited have based its latest Net Zero Plan on a runway opening in 2030, and we have assumed no temporary capacity relaxation on the existing runways before then. As previously assumed, the additional new runway capacity is expected to be phased in over 10 years from the date the new runway is operational. The capacity of the full scheme is limited to the additional 260,000 ATMs assessed by the Airports Commission in their 2015 recommendations.

3.19 This modelling scenario is not therefore a prediction of what the Department of Transport thinks will happen with future capacity expansion but acts as a reasonable upper bound of possible future airport capacity levels and therefore associated UK aviation emissions. Its purpose is limited to providing a consistent basis to better test the potential effectiveness of measures to meet net zero.

3.20 The capacity assumptions for runways and for passengers (only where a planning constraint exists) are shown in Annex D and in footnote 21. These capacities should not be confused with forecast throughput. Outside of the South East of England, where airports tend to be more crowded, most regional capacities are notional and far exceed current and predicted usage.

Aligning airport throughputs to capacity

3.21 There have been significant model improvements in the capacity constrained modelling to align forecast throughputs to input capacities at those airports which have become full. There are two main reasons behind this improvement.

1. The new practice of specifying terminal (passenger) capacities only where there is a clear planning-imposed constraint. In many cases this eases the computational requirement of finding a converged solution which satisfies a dual passenger and terminal constraint. Where no terminal capacity is entered, detailed modelling of average aircraft loads over time (allowing for dynamic response to demand changes in aircraft seat capacity and passenger load factor) results in effective passenger throughputs being controlled by the runway capacity. Overall, this does not greatly

[21] See Annex D for current assumed annual airport capacities. Airport capacities have only been updated from the previous consultation where there have been planning decisions, new airport planning applications or airports publishing development plans for public consultation since the previous review in 2018. The change in modelling capacity (see paragraph 3.16) now also means there is no need to state passenger capacities where no planning limitation is in place.

change the balance between runway and terminal usage at constrained airports relative to our previous forecasts.

2. Software platform upgrades have permitted the introduction of machine learning techniques into the ‘goalsearch’ algorithm used to find system-wide converged market clearing shadow cost prices at over-capacity airports.[22] The search for shadow costs is also improved by greater stability in the required re-calculation of aircraft loads (through the aircraft sizing graphs in the ATM model) undertaken when a trial converged solution is undertaken.

3.22 As a result of these changes the tolerances around the input capacities are now much tighter than in previous model versions. For example, at Heathrow, converged throughput is now generally within +/- 1,000 ATMs for both the 480,000 current ATM cap and the 740,000 ATMs enabled by a third runway.

[22] See UK aviation forecasts 2017 (publishing.service.gov.uk) paragraphs 2.57-2.61 for more description of the role of shadow costs in solving to input airport capacities.

4. Modelling the UK aircraft fleet

4.1 The Fleet Mix Model (FMM) forecasts the type of aircraft that will be used in any particular year to service future demand. The FMM has been further developed from that described in the 2017 forecasts. This model continues to take base year (2018) age distributions of ATMs by specific aircraft type at all the main UK airports and forecast the future changes to that composition, having applied national level assumptions about:

- the typical retirement age of each aircraft type
- the split of new aircraft entering the fleet each year

4.2 Since the last forecast publication, the FMM has been integrated inside the NAPAM calculation of ATM demand. Whereas previously the FMM was applied to scheduled, charter and low cost carrier (LCC) airline type split into six seat band groups, the FMM is now applied at a more disaggregate and targeted manner within NAPAM's ATM model at the route level. This is done at the same time as the number of ATMs are calculated from the number of seats required to meet demand on a specific route.[23]

[23] The NAPAM ATM model is described in the 2017 Aviation Forecasts report. The six seats bands were 0-70, 71-150, 151-250, 251-350, 351-500 and 500+ seats. In practice the final large seat band became virtually unused as airline operational practices changed.

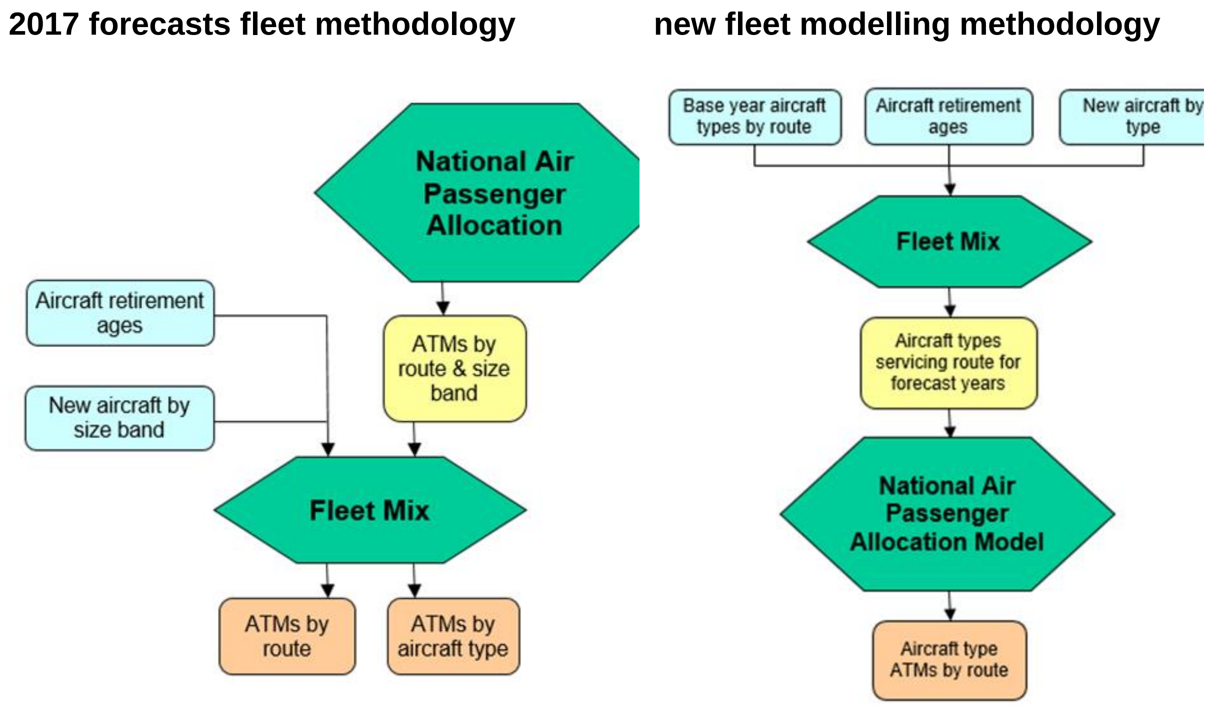


Figure 8 Incorporation of the Fleet Mix Model into NAPAM

4.3 Previously the same expected fleet composition for each model year had been applied to each of the three airline types and six seat band range combination. Now each of the current 135 airline and route specific aircraft sizing graphs in NAPAM's ATM model holds and applies the present and future fleet composition. This integration has delivered several advantages:

- increased granularity – fleets are now annually airport and route specific
- observed aircraft types by route are now a base year model input directly linking aircraft type to seats demanded by route
- extra functionality allowing entire aircraft types to be retired on a set date e.g. the recent retirement of all 747s
- greater precision on the future types of aircraft carried forward into the carbon modelling

4.4 Different scenarios for carbon abatement will produce some changes in the types of aircraft modelled, and some scenarios will explicitly model the introduction of different types of new generation aircraft into the fleet.

Model performance aircraft types

4.5 Prior to the Jet Zero Consultation, the department updated the fleet mix component of the aviation model to better reflect the age profile of aircraft operating in the UK in the years immediately before the pandemic. This update combined registration details of all 2.23m commercial aircraft movements recorded by the CAA at UK airports in 2017 with a current fleet inventory database to produce an updated age distribution of the active UK fleet. All retirements by aircraft type in the period 2014-2017 were analysed to produce a current UK specific retirement age profile by aircraft type. The future supply pool was also updated by analysis of manufacturer's aircraft order books.[24] Having used the 2017 data on fleet age distribution, expected aircraft retirement ages and expected replacements from the future supply pool, the new FMM was validated against CAA records of the fleet operating at UK airports in 2019.

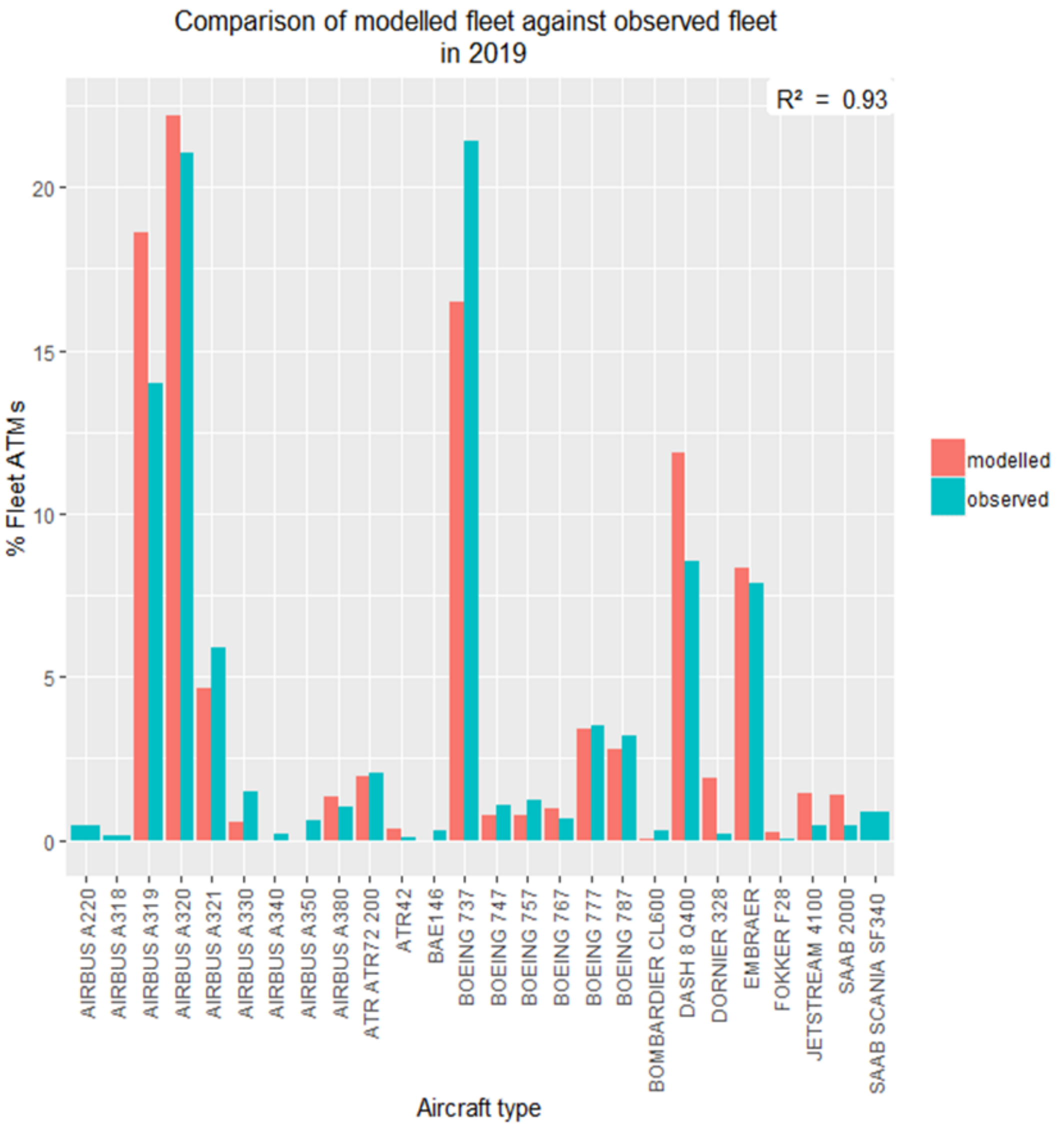


Figure 9 Comparison of predicted (modelled) and observed aircraft types, 2019

[24] All UK aircraft movements with registration mark data were provided by the CAA. The IBA iQ subscription database provided data on inventory of aircraft registrations with associated information such as model type, manufacturer, operator/owner details, manufacture year, seating configuration and activity status. IBA iQ order backlog databases provided the detail on ordered aircraft model, operators, engines, scheduled delivery dates and status of orders.

4.6 Figure 9 shows the fleet validation for 2019 at the UK national level. Across the entire fleet operating in 2019 the model provides a reasonable match with aircraft observed in CAA aircraft movement statistics.[25] There is an evident 5% shortfall of modelled Boeing 737s. This is offset by a surplus of Airbus A319 and A320s. In practice up to 9 aircraft types and type variants can operate some of the busiest routes or groups of modelled routes.[26] These tend to be highly competitive short-haul routes and groups of routes operated by the major low cost carriers. In terms of CO2e emissions modelling, these aircraft types have very similar fuel burn rates and so there is little if any distortion in the emissions modelling. Likewise, the excess of the modelled Dash-8, operated until 2020 principally by Flybe, which is offset by several other types of turboprops.[27] Short-haul turboprop aircraft are small (nearly always under 100 seats) and relatively low CO2e emitters, and so again there is little impact on the CO2e emissions modelling. This is illustrated by the table below which applies the department's CO2 and fuel burn models to the 2019 CAA route and aircraft-type ATM statistics.

	%ATM-Kms	CO2
Wide-bodied jet 4 engines	9%	21%
Wide-bodied jet 2 engines	36%	46%
Narrow-bodied jet	51%	32%
Turbo-prop	3%	1%
Others	1%	0%

4.7 ATM-kms travelled are an important indicator of potential CO2e impacts, but, as the table of fuel burn modelling applied to aircraft type outturn for 2019 illustrates, the relationship is far from linear. The department's CO2e modelling is discussed in the next chapter.

Aircraft fleet replacement modelling

4.8 As described above, the incorporation of route specific fleet modelling into NAPAM allows a more granular application of the forecast fleet turnover.

[25] In addition to this national comparison the 2019 model validation process includes more detailed checks on model performance with respect to numbers of ATMs, aircraft sizes in seats and passenger loads on a (NAPAM airport – zone) route level basis.

[26] Route group zones in NAPAM representing collections of individual smaller routes to destinations in a region.

[27] A turboprop is a hybrid engine that provides jet thrust and drives a propeller. It is used in the UK on domestic and short-haul passenger routes.

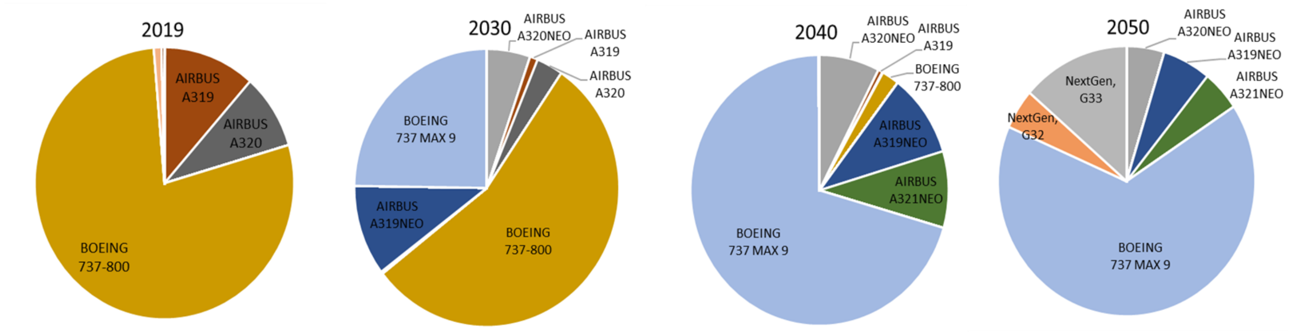
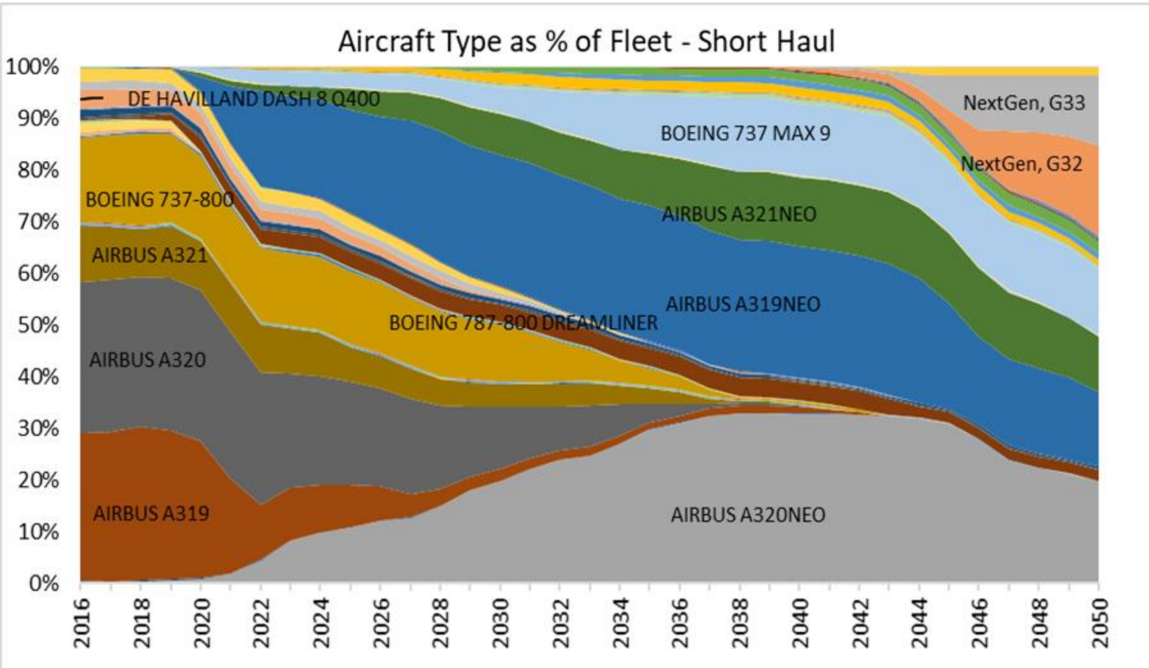


Figure 10 Fleet evolution on the NAPAM Stansted – Iberian Peninsula route forecasts

4.9 The future supply pool assumptions about replacement aircraft types and their potential fuel efficiency are essentially those used in the 2017 forecasts report. As described below modifications have only been made to these assumptions when there has been a clear and permanent change to the pattern of retirement patterns following the disruption to the airline industry caused by the COVID-19 pandemic.

4.10 While Figure 10 above illustrated the fleet replacement on a specific route, Figure 11 below illustrates the principle of how in the full model total short-haul and long-haul fleets evolve over time. This is the baseline model version. The companion document Jet Zero: further technical consultation details where and how these initial fleet mixes could develop differently in the forecast period.



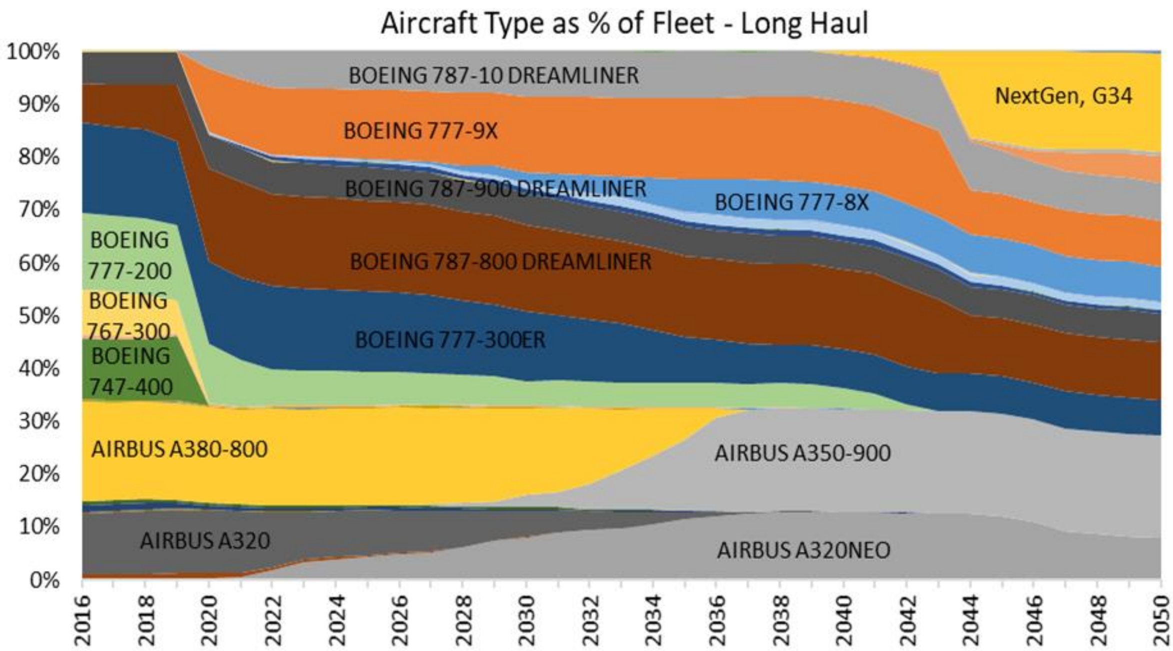


Figure 11 Baseline short and long haul fleet composition by year (illustrative)

4.11 The COVID-19 pandemic is likely to have had some impact on the fleets utilised by the airlines at UK airports. In previous downturns in aviation demand, airlines have reacted by retiring their least fuel-efficient aircraft. However, it is too early to establish with reliable data exactly how the current profile of the fleet has changed in response to recent circumstances. It is therefore premature to comprehensively review and update the assumed fleet age and replacement profiles. However, where there has already been clear evidence of the operational response by airlines, we have made limited updates to the base fleet. These include:

- bringing forward the retirement of old widebody aircraft – notably the Boeing 747
- retiring the Boeing 767 as a significant carrier in 2020
- bringing forward the introduction of more of the fuel-efficient types, e.g. the Boeing 787 Dreamliner, Airbus A350 and the next generation Boeing 777
- recognising that A380 production ended in 2021 and these aircraft leave the fleet in 2030s as they reach retirement age and causing a step change in fleet composition in the 2040s as the original widebody replacements start to retire.

4.12 Annex G shows graphically the evolution of the baseline aircraft type supply pool for the major passenger aircraft manufacturers.

Passenger load factors

4.13 The future size and passenger load factors of aircraft will be a key determinant of the number of aircraft needed to meet future demand. In recent years increased load factors have played a significant role in increasing practical capacity – in effect allowing airports to make better use of existing runway capacity in terms of numbers of passengers uplifted. Potentially higher load factors mean using less ATMs to meet demand and consequently less CO2e emissions. This latest version of the model accurately represents the recent rise in passenger load factors. There is a good model performance in reproducing 2019 aircraft loadings, as shown in Annex F. This updating is a key change affecting forecast CO2e emissions in comparison with those presented in the original Jet Zero Consultation analysis.

4.14 At the UK national level in the 10 years before 2020, the average size of aircraft used on commercial passenger flights has increased by 5% from 152 to 159 seats. At the same time the average passenger load per aircraft has increased by 11% from 118 to 131 passengers per aircraft.[28] So although the size in terms of seats has been increasing, the increase in load factors achieved by the airlines has arguably been even more significant in driving up average aircraft loadings in recent years.

4.15 The methodology behind the input of load factor growth assumptions has not been reviewed since the department published its forecasts in 2013. In light of recent developments, the method has been updated to better account for the observed trends while retaining the same rules on the limits to load factor growth.

- Observed CAA data for each modelled route is used for 2016-2019.[29] The ‘old’ 2017 forecasts model used observed data for 2016 only and by 2019 observed average load factors were 5% higher than those previously forecast. This uplift has a significant impact on the future numbers of ATMs forecast.[30]

- Annual growth increments in load factor updated are now calculated using observed growth rates from 2010-2019 for each route allowing historic trends for specific routes to be extended, but subject to a 95% cap.

- In previous forecasts load factors were forecast to grow in the period 2016-2030. Now they are forecast in line with route level historical statistical trends for the same 2016-2030 period. They remain subject to the same ultimate cap of 95% for both international and domestic flights.

- A setting which had allowed the modelled load factor to be grown by a further 2% spread over 10 years at any airport which reached runway capacity (i.e. experienced the onset of shadow costs) has been dropped. This was primarily because it was difficult to gather robust statistical evidence that such an impact occurred at over-capacity UK airports or of the duration of any such effect.

- The growth in load factors in the last decade has clearly been interrupted by the COVID-19 pandemic. But for the purposes of this work, given clear evidence of the

[28] The impact of rising load factors in the five years before 2020 is even more marked at Heathrow where the average load per aircraft has increased by 6% from 159 to 169 while the size of aircraft used to deliver this has decreased from 218 to 211 seats (-3%).

[29] Route here means a UK airport to either other UK airports or the 67 international zones in the NAPAM zone system.

[30] Outturn load factor data reviewed against forecast outputs for 2015-2019 showed that input assumptions tended to underestimate the load factor growth while the model was generally performing well in predicting changes in aircraft size.

importance of higher load factors to modern airline business models, it is assumed that load factors will revert to the previous trend.

5. Modelling aircraft CO2e emissions

Introduction

5.1 Aviation CO2e emissions are directly related to the amount and type of aviation fuel consumed. There are therefore four key drivers of aviation CO2e emissions:

- total aviation demand driven principally by levels of national and international economic activity and passenger sensitivity to the level of air fares including the cost of fuel burnt and carbon prices in the fares – this is the output of NAPDM described in Chapter 2;
- total distance flown: this comprises the volume and average distance of flights from the UK, in turn driven by passenger demand after accounting for airport capacity constraints – this is the output of NAPAM described in Chapter 3;
- fuel efficiency of aircraft: the fuel required to fly a given total distance will fall as aircraft efficiency driven by technological and operational improvements improves – efficiency gains derive from the turnover of the regular fleet as output in the NAPAM Fleet Mix Model and described in Chapter 4; and,

5.2 type of fuel or power utilised by aircraft: the CO2 emissions associated with a given amount of fuel burn will fall as the penetration of alternative fuels and power sources increases – these are a principal focus of the abatement strategy scenarios and are discussed in detail in Jet Zero: further technical consultation.

5.3 The CO2e modelling component in the department's aviation modelling suite is essentially unchanged from that used in the Jet Zero Consultation (July 2021). The key inputs to the fuel burn and CO2e forecasts are NAPAM forecasts of annual ATMs for each airport, by route and by forecast aircraft type. As described in the previous chapter, the aircraft type prediction is now made inside NAPAM at the route level rather than the previous exogenous Fleet Mix Model.

5.4 NAPAM now forecasts ATMs by specific aircraft types. On each route these aircraft types flying in and out of the UK are output as seat-kilometres. Distances applied are the 'great circle' distances, a common metric for aviation purposes, representing the shortest air travel distance between two airports taking account of the curvature of the earth. Separately in the department's CO2 model, the actual distance flown is increased above the great circle distance because of sub-optimal airspace routeing and other en-route air traffic control inefficiencies such as stacking for landing at airports during periods of congestion. An adjustment factor is therefore applied to uplift the distance flown by 5% for short-haul, and 6% for long-haul destinations as recommended in a model review by Ricardo Energy & Environment.[31]

5.5 In 2018 the department, jointly with the CCC, commissioned research from a consortium of academics and industry experts to examine the scope for fuel efficiency improvements of the fleet used in UK aviation. This work included assessed improvements to engine and airframe design and technologies, operational measures that were within the control of airlines and air traffic management. The research was based around representative aircraft types and methodologies in the department's Fleet Mix Model. We have used this analysis as an input to our modelling of fuel burn and carbon emissions. This research informed the baseline fuel burn technologies and timeframes of new aircraft types in the aircraft replacement supply pools (see Annex G) used in the Jet Zero Consultation and retained in this updated modelling. The generic assumed future aircraft types ('NextGen') shown in Figure 11 in the previous chapter are modelled with fuel efficiencies reflecting this latest research.

Modelling aircraft fuel burn

5.6 The European Environment Agency's (EEA) air pollutant emissions inventory guidebook 2016 has been an established starting point for fuel burn modelling. Fuel burn is measured in kilograms of fuel per aircraft and is broken down to bands of flight distances and the different stages of the flight (e.g. the landing and take-off cycles and cruise stage).[32]

5.7 The EEA inventory is an established and authoritative source of data on aircraft fuel burn rates, and has been significantly enhanced in recent years with many more aircraft types and anonymised actual operational data provided by airlines.[33] It is used for general reference, and for use by parties such as the Convention on Long Range Transboundary Air Pollution (LRTAP) and for reporting to the UNECE Secretariat in Geneva. It is also widely used by ICAO-CAEP in setting environmental policies and standards.

5.8 In the CO2 model, aircraft types and future types are mapped to types for which data is provided in the EEA guidebook or to future generation types. Where data for the specific plane type is not available, it is mapped to a similar 'proxy' type and, where needed, an adjustment made to account for higher/lower fuel efficiency. As part of a review of the CO2e modelling process, Ricardo Energy & Environment provided advice on mapping aircraft types to those in the EEA guidebook. The review also

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[31] This input can be used as a potential decarbonisation lever, but these settings are held constant for the Jet Zero analysis.

[32] Aircraft burn fuel at a greater rate at the start of flights, not just because of take-off and climb out, but because there is more fuel weight to carry.

[33] It is assumed that fuel burn on a 100% loaded jet aircraft will be 5% higher than on a 70% loaded aircraft, due to the increased weight. See *An evaluation of aircraft emissions inventory methodology by comparisons with reported airline data*. Daggett, D. L., D. J. Sutkus Jr., D. P. DuPois, and S. L. Baughcum, 1999: NASA/CR-1999-209480.

advised on adapting guidebook fuel burn models for generic future aircraft types, mapping them to existing types but with an adjustment to account for anticipated performance improvements. Manufacturers' data and the PIANO aircraft design and performance model are used to project the fuel burn rates of new aircraft types expected to enter service soon.

5.9 Apart from taking account of the research jointly commissioned with the CCC on updating likely future aircraft fuel efficiency improvements and the incorporation of the FMM into NAPAM, the fuel burn to CO2e methodology is largely unchanged from the department's 2017 forecasts.

5.10 In common with previous forecasts, a similar approach is taken by forecasting at the national level using the forecast of freighter ATMs which are held constant at 2019 levels. Emissions are projected to grow by combining the number of freighter ATMs, average trip length, and fuel efficiency projections. Fuel efficiency is assumed to follow a similar path to that of equivalent passenger aircraft.

Fuel burn for future aircraft types

Data in the EMEP/EEA air pollutant emission inventory guidebook 2016 has been used to derive rates for fuel burn/distance (in kg/Nm) as a function of flight distance for most currently available aircraft types.

Fuel burn rates for future aircraft types, not contained in the guidebook, have been related to rates of existing aircraft types on the advice of Ricardo Energy & Environment as shown in the examples below for the major model types used in the Jet Zero assessment.

Future aircraft type[34]	Fuel burn
BOEING 737 MAX 9*	B739 -15.0%
AIRBUS A319NEO*	A319 -15.0%
AIRBUS A320NEO*	A320 -15.0%
AIRBUS A321NEO*	A321 – 15.0%
BOEING 777-9X*	B77W – 13.0%
NextGen G31, Post 2030 c1 1-70 seats*	ATR42 -31.5%
NextGen G32, Post 2030 c2 71-150 seats*	B734 -31.5%
NextGen G33, Post 2030 c3 151-250 seats*	B734 -31.5%
NextGen G34, Post 2030 c4 251-350 seats*	B772 -29.5%

* New future type developed from type in the guidebook with advice from Ricardo Energy & Environment

Which emissions are being counted?

5.11 The scope of aviation CO2e could cover many possible sources of emissions. For example, it may be argued that emissions from journeys to and from an airport are 'generated' by the existence of the airport and its services. However, this potentially

[34] Note that the specific Max and Neo variants now replace the 'NextGen G2' types in previous reports on the future composition of the FMM, this is a change in labelling more than a change in the modelling of the fuel burn.

causes double-counting of emissions in different parts of the UK national inventory where surface transport emissions are accounted separately.

5.12 It is also important to recognise that some actions or events that reduce UK inventory aviation CO2e emissions do not necessarily reduce global aviation CO2e emissions (and vice versa). For example, constraining activity at UK hub airports could result in some passengers making transfers via neighbouring continental hub airports instead of the UK, thereby offsetting the reduction in the UK emissions inventory with increases in emissions elsewhere. This is in effect exporting UK aviation emissions and not reducing the global climate impact of the emissions. The scope of the CO2e emissions modelling here is aircraft departing UK airports. The value of using the NAPAM model (see Chapter 3 and the 2017 forecasts report) is that it models the interaction between UK airports and competing continental hub airports. The value of adopting the airport capacity assumptions set out in Chapter 3 is that by representing a plausible maximum practical airport capacity case, it also realistically limits the export of passenger generated aviation emission and provides a suitable precautionary level of UK demand for considering UK aviation abatement strategies.

5.13 The sources of emissions covered in the forecasts in this chapter are set out in the table below. The approach used is consistent with the BEIS outturn estimates and the UNFCCC recommended approach for reporting on CO2e emissions from international aviation. The sources of CO2e included in the forecasts are those using A1-Jet fuel/Kerosene and exclude the light aircraft using aviation spirit/Avgas to reconcile with BEIS bunker fuel returns of A1-Jet fuel. Thus, business jets using jet-fuel are included as part of the residual (see below),[35] but light aircraft including most general aviation are excluded because the fuel is not included in the bunker jet/turboprop fuel returns.

Emissions source	**Included in forecasts?**
All domestic passenger flights within the UK	Yes
All international passenger flights departing UK airports	Yes
All passenger aircraft while on the ground in the UK e.g. taxiing	Yes
All domestic freighter aircraft departing UK airports	Yes
All international freighter aircraft departing UK airports[36]	Yes
All freighter aircraft while on the ground in the UK e.g. taxiing	Yes
Non- scheduled ‘business jets’.	Yes
Avgas using general aviation (non-commercial flights) in UK airspace	No
Military flights	No
Surface access, i.e. passenger and freight journeys to and from a UK airport	No
Non-aircraft airport sources, e.g. terminal power sources and airfield vehicles	No
UK registered aircraft flying from airports not in the UK	No
International flights arriving in the UK	No
Overflights passing through UK airspace	No

[35] Business jet cannot be modelled on a route by route basis and not reported in CAA statistics so have to be treated as part of the bunker fuel ‘residual’ – see below. They are thought to be the largest component of the residual.

[36] Emissions from freight carried in the belly hold of aircraft are captured in the passenger aircraft emissions.

CO2e.

5.14 It should be noted that since the 2017 forecasts were published the metric used by the department for reporting emissions is now by default CO2e (‘CO2 equivalent’) rather than CO2. The department’s model which produces these forecasts is still referred to as the ‘CO2 Model’, but it has been run in its CO2e output mode throughout this analysis.

5.15 In practice when kerosene is burned, small amounts of other greenhouse gases (included in the Kyoto Protocol) are also emitted including methane (CH4) and nitrous oxide (N2O). The emissions forecasts are uplifted accordingly. However, the amounts are small – they equate to around 1% of the global warming potential of the CO2 itself.[37]

Validation of emission forecasts with BEIS bunker fuel data

5.16 The new baseline forecasts using the updated FMM and CO2 models have been validated against base year CO2e actuals for 2019. In common with established national reporting practice, CO2e is counted for departing aircraft only.

5.17 Aviation emission forecasts are adjusted to match the Department for Business, Energy and Industrial Strategy (BEIS) estimate of 2019 outturn (i.e. published) aviation CO2e emissions (using the UNFCCC reporting method),[38] as reported in the National Atmospheric Emissions Inventory (NAEI). The BEIS estimates of outturn CO2e emissions from aviation are based on the amount of aviation fuel uplifted from bunkers at all UK airports.

5.18 In the modelling, the adjustment also reflects any difference in definition, including the absence from the modelling of the minor types of traffic such as business jets which are difficult to model, or flights from very small airports that are not included in the model.[39] The department adjusts to BEIS bunker-fuel based returns with a supplementary residual which is added to the modelled CO2e and held constant throughout the forecast period.

5.19 The reconciliation of 2019 modelled estimates against 2019 actuals, and the resulting residual adjustment, is shown below.

Million tonnes of CO2e	International	Domestic
Bunker CO2e actual 2019	36.7	1.4
Model CO2e 2019	35.1	1.3
Difference or ‘residual’	1.6	0.1

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[37] The exact CO_2 to CO_2e factor applied to all CO_2 emissions is 1.01035.

[38] The 'forecast' for 2015 is about 1.0MtCO_2e (3%) below the latest revised BEIS estimate for that year. This residual amount is added back into the forecasts. A similar procedure is required by BEIS when converting DUKES air fuel sales data to CO_2e bunker emissions data for domestic and international civil aviation. The adjustment is held constant throughout the model period.

[39] In addition to allowing for aircraft and fuel burn modelling error, the residual must also accommodate any asymmetries in inbound and outbound flight refuelling caused by the practice of ‘tankering’. It excludes light aircraft using Avgas – see above.

5.20 A positive CO_2e residual value is to be expected. The scale of the residual is well within the expected range and gives confidence in the more precise and disaggregate aircraft fleet modelling within NAPAM and the fuel burn models.

Annex A: Changes to NAPDM demand elasticities

	Previous model (using data to 2008)		Current model (using data to 2017)	
	Income elasticity	Price elasticity	Income elasticity	Price elasticity
UBD (UK business domestic)	0.9	-0.3	1.1	-0.2
ULD (UK leisure domestic)	1.4	-0.7	1.0	-1.0
UBSE (UK business Southern Europe)	1.1	-0.3	0.6	-0.2
UBRoE (UK business Rest of Europe)	1.1	-0.3	1.1	0.0
UBOECD (UK business other OECD)	0.9	0.0	0.1	0.0
UBRoW (UK business Rest of the World)	0.9	0.0	0.4	-0.6
ULSE (UK leisure Southern Europe)	1.2	-0.7	1.0	-1.1
ULRoE (UK leisure Rest of Europe)	1.2	-0.7	1.0	-1.1
ULOECD (UK leisure other OECD)	1.2	-0.3	1.3	-1.1
ULRoW (UK leisure Rest of the World)	1.4	-0.6	2.0	-0.9
FBSE (Foreign business Southern Europe)	1.0	-0.2	1.1	-0.1
FBRoE (Foreign business Rest of Europe)	1.0	-0.2	0.7	-0.3
FBOECD (Foreign business other OECD)	0.5	-0.2	0.9	0.0
FBRoW (Foreign business Rest of the World)	0.7	0.0	1.2	-0.3
FLSE (Foreign leisure Southern Europe)	1.1	-0.8	2.6	-1.1
FLRoE (Foreign leisure Rest of Europe)	1.1	-0.8	1.9	-1.1
FLOECD (Foreign leisure other OECD)	0.5	-0.3	1.1	-1.1
FLRoW (Foreign leisure Rest of the World)	0.5	-0.2	2.1	-0.9
Cells in yellow reflect overrides. Overrides are applied where a market's data are limited. When an override takes place, we refer to the elasticities of other similar markets with more robust data and validate with economic theory and existing literature. In the markets where a structural break exists, it is the elasticities post the structural break that are shown. Where elasticities do not relate to a specific market, they have been weighted.				

	Previous model (using data to 2008)		Current model (using data to 2017)	
	Income elasticity	Price elasticity	Income elasticity	Price elasticity
Overall	1.1	-0.6	1.2	-0.9
All business	1.0	-0.2	0.9	-0.2
All leisure	1.2	-0.6	1.3	-1.1
Domestic	1.2	-0.5	1.1	-0.6
Southern Europe	1.2	-0.7	1.2	-1.0
Rest of Europe	1.1	-0.6	1.2	-0.9
OECD	0.9	-0.3	1.1	-0.9
Rest of World	1.1	-0.4	1.8	-0.9
All UK residents	1.2	-0.6	1.1	-0.9
All foreign residents	0.9	-0.5	1.6	-0.9

Where elasticities do not relate to a specific market, they have been weighted

Annex A footnote: NAPDM time series fare inputs

Data	Source	Aggregation level	Unit
Exchange rates (short-term)	OBR	Year	$/£ (2015 prices)
Exchange rates (long-term)	Assumed no change	Year	$/£ (2015 prices)
Oil prices	BEIS	Year	$ / barrel (2015 prices)
Carbon prices UK ETS	DfT series	Year, UK / EEA	£/CO2 (2015 prices)
Carbon prices CORSIA	DfT series[40]	Year, long-haul	£/CO2 (2015 prices)
Air Passenger Duty (APD)	HMRC	Year, domestic / global region	£ (2015 prices)
Non-fuel costs changes	DfT calculation based on trends in CAA historic data	Year, short-haul / long-haul	Annual percentage change
Load factors	NAPAM	Year, domestic / global region	Percentage
Fuel efficiency	NAPAM	Year, domestic / global region	Seat km per tonne of fuel
Jet fuel price parameters: Relationship between oil price and fuel cost (fuel cost = α + βxOilPrice)	DfT regression	N/A	Constant (α): $ (2015 prices) Coefficient (β): Applied to oil price in $ / barrel (2015 prices) Result is fuel price $ / tonne of fuel (2015 prices)
Hedging assumptions	DfT assumption following review of airline statutory accounts	Year (3 years only)	Proportion of oil price applied by year (must sum to 100%)
Starting level of non-fuel costs	IPS fares data / DfT calculation	Year	£ per seat km in model base year (2015 prices)
Average trip length	NAPAM	Domestic / global region, journey purpose	Km
CO2e content of fuel (carbon intensity)	DfT CO2 model		

[40] More information on how these were derived is in *Jet Zero: further technical consultation*, Chapter 2 and Annex B.

Annex B: NAPAM International zone definitions

Zone code	Zone Name	Haul	Former zone	Changed?	NAPDM	EU/ETS
2001	US East	L	513	N	OECD	
2002	US West	L	512	N	OECD	
2003	Canada East	L	503	N	OECD	
2004	Canada West	L	502	N	OECD	
2005	Caribbean	L	522	Y	RoW	
2006	Mexico	L	522	new	OECD	
2007	Chile	L	522	new	OECD	
2008	South America (other)	L	522	Y	RoW	
2009	Australia & New Zealand	L	526	Y	OECD	
2010	South Pacific (other)	L	526	Y	RoW	
2011	Africa West	L	519	N	RoW	
2012	Africa East	L	520	Y	RoW	
2013	Africa South	L	521	N	RoW	
2014	China (Incl.Hong Kong)	L	525	Y	RoW	
2015	Japan & South Korea	L	525	new	OECD	
2016	Far East (other)	L	525	Y	RoW	
2017	Indian Sub-continent	L	524	Y	RoW	
2018	Asia (other)	L	518	Y	RoW	
2019	Middle East	L	523	Y	RoW	
2020	Israel	S	523	new	OECD	
2021	Russia & non-EU former Soviet	S	518	Y	RoE	
2022	Ireland	S	511	N	RoE	EU
2023	Channel Islands	S	527	N	RoE	EU
2024	France	S	505	Y	RoE	EU
2025	Belgium & Luxembourg	S	501	N	RoE	EU
2026	Netherlands	S	510	N	RoE	EU
2027	Germany	S	506	Y	RoE	EU
2028	Scandinavia (EU)	S	516	Y	RoE	EU
2029	Baltic States	S	518	new	RoE	EU
2030	Poland	S	518	new	RoE	EU
2031	Central Europe (EU)	S	517	Y	RoE	EU
2032	Bulgaria & Romania	S	518	new	RoE	EU
2033	Iberian Peninsula	S	514	Y	SE	EU
2034	Canary Islands	S	504	N	SE	EU

Zone code	Zone Name	Haul	Former zone	Changed?	NAPDM	EU/ETS
2035	Italy	S	509	Y	SE	EU
2036	Greece-other, EU eastern Med	S	507	Y	SE	EU
2037	Iceland (& Greenland)	S	508	N	RoE	(ETS)
2038	Norway	S	516	new	RoE	(ETS)
2039	Switzerland (& Liechtenstein)	S	517	new	RoE	
2040	Non-EU Balkan	S	515	new	RoE	
2041	Turkey	S	515	new	SE	
2042	African Mediterranean	S	519/520	new	RoW	
2043	Dublin	S	529	N	RoE	EU
2044	Brussels	S	532	N	RoE	EU
2045	Berlin	S	506	new	RoE	EU
2046	Dusseldorf	S	534	N	RoE	EU
2047	Hamburg	S	545	N	RoE	EU
2048	Munich	S	537	N	RoE	EU
2049	Copenhagen	S	535	N	RoE	EU
2050	Stockholm	S	540	N	RoE	EU
2051	Budapest	S	517	new	RoE	EU
2052	Vienna	S	541	N	RoE	EU
2053	Alicante	S	514	new	SE	EU
2054	Barcelona	S	543	N	SE	EU
2055	Madrid	S	536	N	SE	EU
2056	Malaga	S	514	new	SE	EU
2057	Lisbon	S	546	N	SE	EU
2058	Milan	S	539	new	SE	EU
2059	Rome	S	538	new	SE	EU
2060	Athens	S	544	N	SE	EU
2061	Oslo	S	542	N	RoE	(ETS)
2062	Geneva	S	547	N	RoE	(ETS)
2063	Zurich	S	533	N	RoE	(ETS)
2064	Paris CDG	S	528	N	RoE	EU
2065	Amsterdam	S	530	N	RoE	EU
2066	Frankfurt	S	531	N	RoE	EU
2067	Dubai	L	523	Y	RoW	
2068	UK offshore	S	599	N	UK	

Annex C: UK modelled airports in NAPAM

IATA	New_code	Name	Region	Old_code
LGW	3001	Gatwick	London & SE	471
LHR	3002	Heathrow	London & SE	473
LCY	3003	London City	London & SE	478
LTN	3004	Luton	London & SE	479
STN	3005	Stansted	London & SE	486
SOU	3006	Southampton	Other SE	485
SEN	3007	Southend	Other SE	484
BOH	3008	Bournemouth	South-West	465
BRS	3009	Bristol	South-West	466
EXT	3010	Exeter	South-West	470
NQY	3011	Newquay	South-West	482
CWL	3012	Cardiff	Wales	467
NWI	3013	Norwich	East	483
BHX	3014	Birmingham	Midlands	464
EMA	3015	East Midlands	Midlands	468
DSA	3016	Doncaster Sheffield	North	491
HUY	3017	Humberside	North	474
LBA	3018	Leeds/Bradford	North	476
LPL	3019	Liverpool	North	477
MAN	3020	Manchester	North	480
NCL	3021	Newcastle	North	481
MME	3022	Teesside	North	487
ABZ	3023	Aberdeen	Scotland	461
EDI	3024	Edinburgh	Scotland	469
GLA	3025	Glasgow	Scotland	472
INV	3026	Inverness	Scotland	475
PIK	3027	Prestwick	Scotland	492
BHD	3028	Belfast City	Northern Ireland	463
BFS	3029	Belfast International	Northern Ireland	462
XX1	3030	Spare1	n/a	488
XX2	3031	Spare2	n/a	489
XX3	3032	Spare3	n/a	490
CDG	3033	Paris CDG	Overseas Hub	493
AMS	3034	Amsterdam	Overseas Hub	494
FRA	3035	Frankfurt	Overseas Hub	495
DXB	3036	Dubai	Overseas Hub	496

Note: NAPAM only models the busier UK airports which had some regular international commercial passenger air services operating in 2019.

Annex D: Airport runway capacity assumptions for carbon modelling

Annual Capacities		Annual ATMs (000s)				mppa Annual passengers (if in use)			
		2019	2030	2040	2050	2019	2030	2040	2050
Gatwick	LGW	291	346	383	386				
Heathrow*	LHR	480	505	740	740				
London City*	LCY	111	151	151	151	6.5	11.0	11.0	11.0
Luton	LTN	160	210	210	210	18.0	32.0	32.0	32.0
Stansted*	STN	259	259	259	259	35.0	43.0	43.0	43.0
Southampton	SOU	150	150	150	150	2.5	3.0	3.0	3.0
Southend*	SEN	53	53	53	53				
Bournemouth	BOH	150	150	150	150				
Bristol	BRS	150	150	150	150	10.0	12.0	12.0	12.0
Exeter	EXT	150	150	150	150				
Newquay	NQY	75	75	75	75				
Cardiff	CWL	105	150	150	150				
Norwich	NWI	175	175	175	175				
Birmingham	BHX	206	206	206	206				
East Midlands	EMA	264	264	264	264				
Doncaster Sheffield*	DSA	57	57	57	57				
Humberside	HUY	150	150	150	150				
Leeds/Bradford	LBA	150	150	150	150	5.0	7.0	7.0	7.0
Liverpool	LPL	213	213	213	213				
Manchester	MAN	324	400	500	500				
Newcastle	NCL	213	226	226	226				
Teesside	MME	150	150	150	150				
Aberdeen	ABZ	175	225	225	225				
Edinburgh	EDI	150	225	230	261				
Glasgow	GLA	226	226	226	226				
Inverness	INV	150	150	150	150				
Prestwick	PIK	150	150	150	150				
Belfast City*	BHD	48	48	48	48				
Belfast International	BFS	260	260	260	260				
Paris	CDG	690	690	690	690				
Amsterdam	AMS	510	630	750	750				
Frankfurt	FRA	700	700	700	700				
Dubai	DXB	560	1360	1760	1760				

* assumed planning condition on ATMs

>0 = assumed condition on passenger numbers

Note: NAPAM only forecasts to capacity at the busier UK airports which had some regular international commercial passenger air services operating in 2019. See also paragraphs 3.18 to 3.22 for commentary on the updating of these capacity assumptions.

Annex E: Model performance – passengers at airports 2019

2019		Actual mppa	Modelled mppa
Gatwick	LGW	46.6	47.5
Heathrow	LHR	80.9	81.9
London City	LCY	5.1	4.8
Luton	LTN	18.2	17.3
Stansted	STN	28.1	29.9
Southampton	SOU	1.8	1.6
Southend	SEN	2.0	1.4
Bournemouth	BOH	0.8	0.7
Bristol	BRS	9.0	8.4
Exeter	EXT	1.0	1.0
Newquay	NQY	0.5	0.5
Cardiff	CWL	1.7	1.4
Norwich	NWI	0.5	0.5
Birmingham	BHX	12.6	11.1
East Midlands	EMA	4.7	5.4
Doncaster Sheffield	DSA	1.4	1.3
Humberside	HUY	0.2	0.2
Leeds/Bradford	LBA	4.0	4.5
Liverpool	LPL	5.0	4.2
Manchester	MAN	29.4	29.2
Newcastle	NCL	5.2	5.4
Teesside	MME	0.1	0.2
Aberdeen	ABZ	2.9	2.6
Edinburgh	EDI	14.7	14.0
Glasgow	GLA	8.8	8.4
Inverness	INV	0.9	0.7
Prestwick	PIK	0.6	0.3
Belfast City	BHD	2.5	2.6
Belfast International	BFS	6.3	5.2
UK Airport Totals		295.7	292.0

r^2 = 0.99885

Paris	CDG	76.2	76.6
Amsterdam	AMS	71.7	71.9
Frankfurt	FRA	70.6	70.2
Dubai	DXB	86.4	86.7
Foreign Hub Totals		304.8	305.5

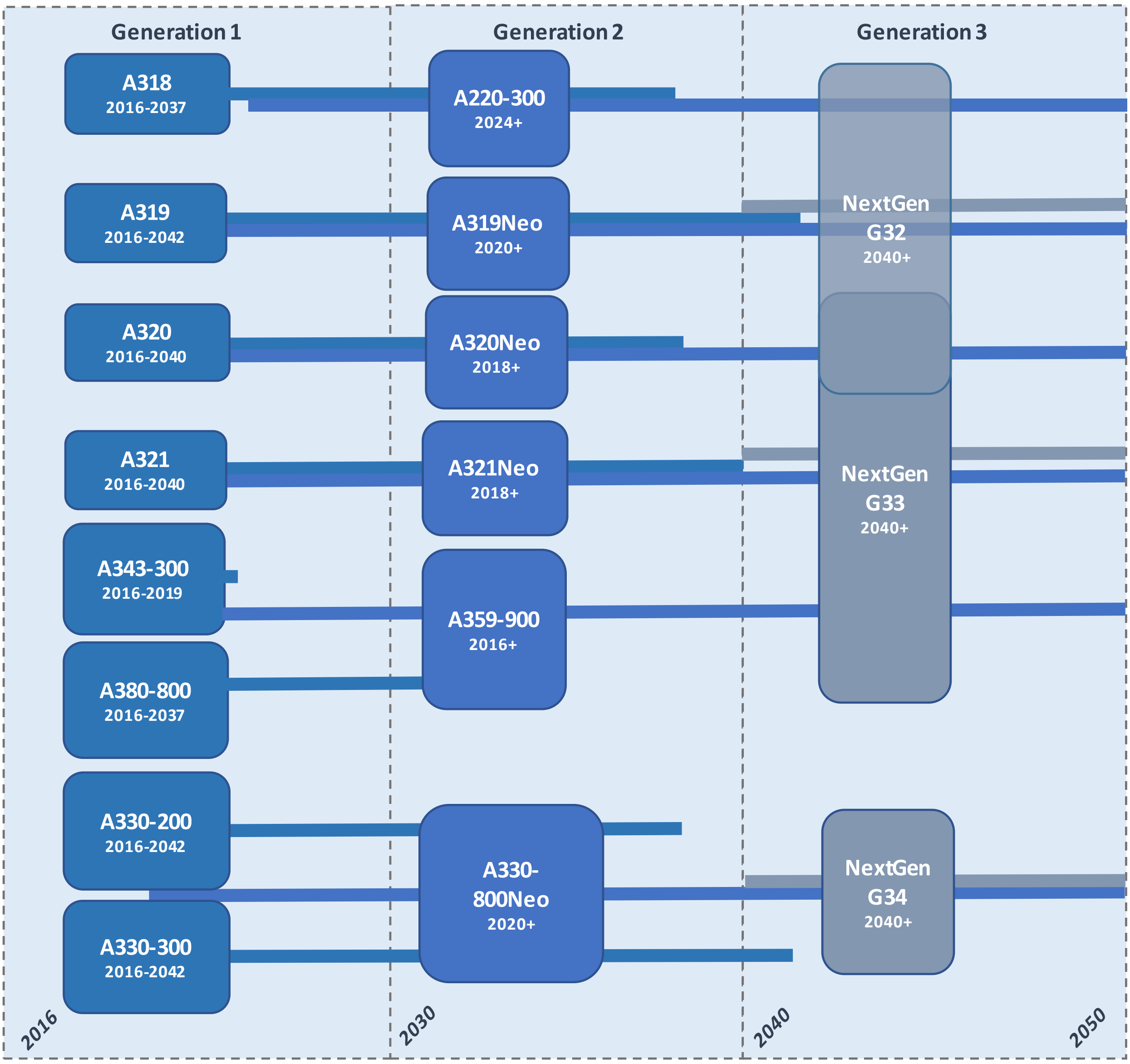
r^2 = 0.99850

Annex F: Model performance – aircraft movements (ATMs) and aircraft passenger loads at UK airports 2019

2019		ATMs '000s Actual	ATMs '000s Modelled	Passenger loads Actual	Passenger loads Modelled
Gatwick	LGW	283	288	165	165
Heathrow	LHR	480	477	170	173
London City	LCY	81	81	64	59
Luton	LTN	113	120	165	146
Stansted	STN	184	196	164	162
Southampton	SOU	33	33	55	47
Southend	SEN	19	11	108	139
Bournemouth	BOH	5	4	162	166
Bristol	BRS	63	60	144	141
Exeter	EXT	15	13	78	81
Newquay	NQY	8	9	68	66
Cardiff	CWL	17	19	105	76
Norwich	NWI	20	21	53	41
Birmingham	BHX	103	93	127	122
East Midlands	EMA	56	64	142	134
Doncaster Sheffield	DSA	10	9	148	140
Humberside	HUY	7	8	47	48
Leeds/Bradford	LBA	30	33	134	137
Liverpool	LPL	35	31	153	143
Manchester	MAN	196	202	152	147
Newcastle	NCL	40	44	131	124
Teesside	MME	4	4	41	40
Aberdeen	ABZ	78	83	66	49
Edinburgh	EDI	127	127	125	119
Glasgow	GLA	79	80	127	120
Inverness	INV	13	13	90	69
Prestwick	PIK	5	2	149	137
Belfast City	BHD	35	42	71	62
Belfast International	BFS	47	42	146	137
UK Airport Totals		2182	2211	145	141
		r^2 = 0.99791		r^2 = 0.94521	

Annex G: Fleet model aircraft supply pools

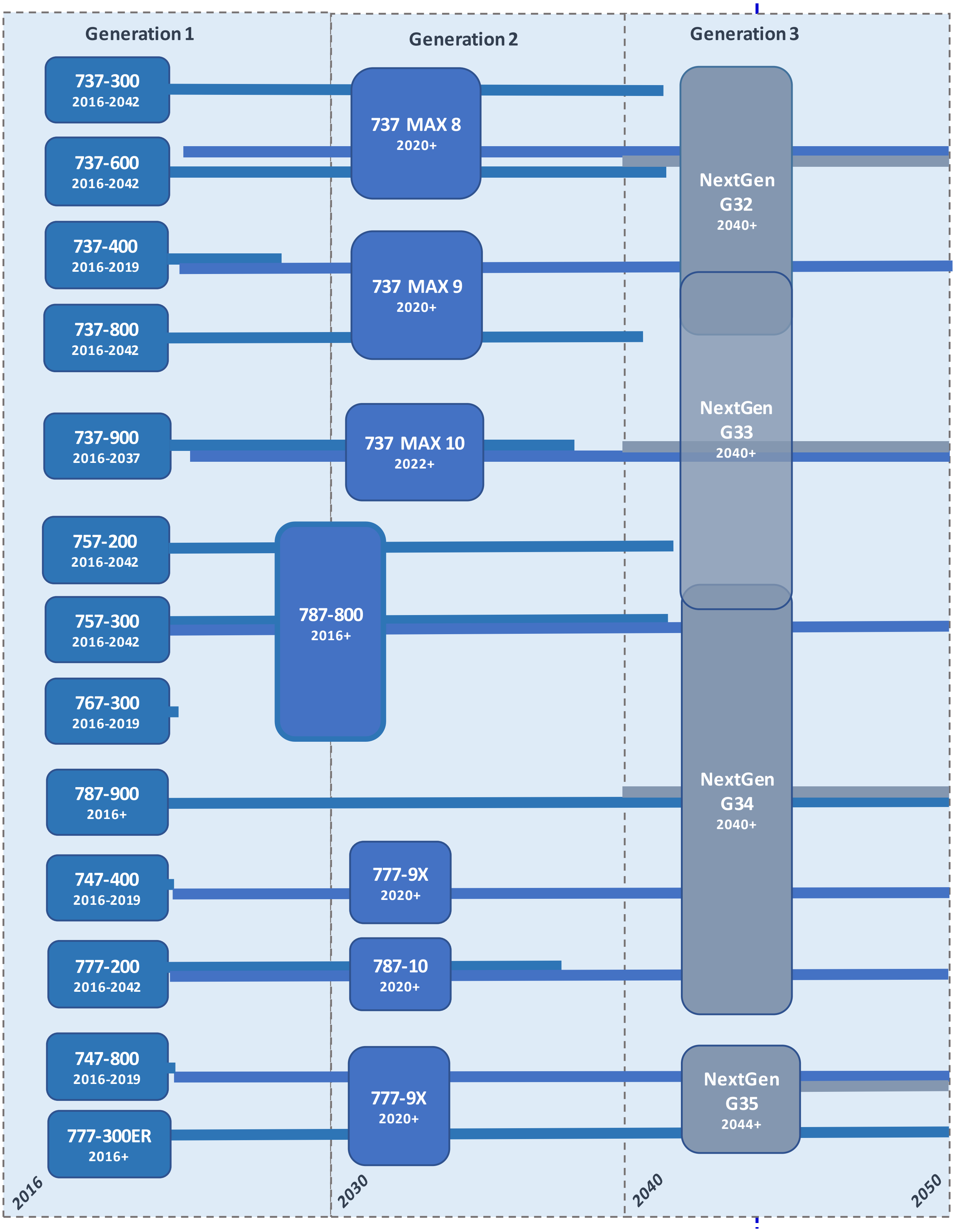
Airbus



NextGen Code (*GYC*)		Introduction Date		Seat Class	
Y	introduction date	2	post 2030	1	0 - 70
C	Seat Class	3	post 2040	2	71 -150
				3	151 - 250
				4	250 - 350
				5	350 - 500

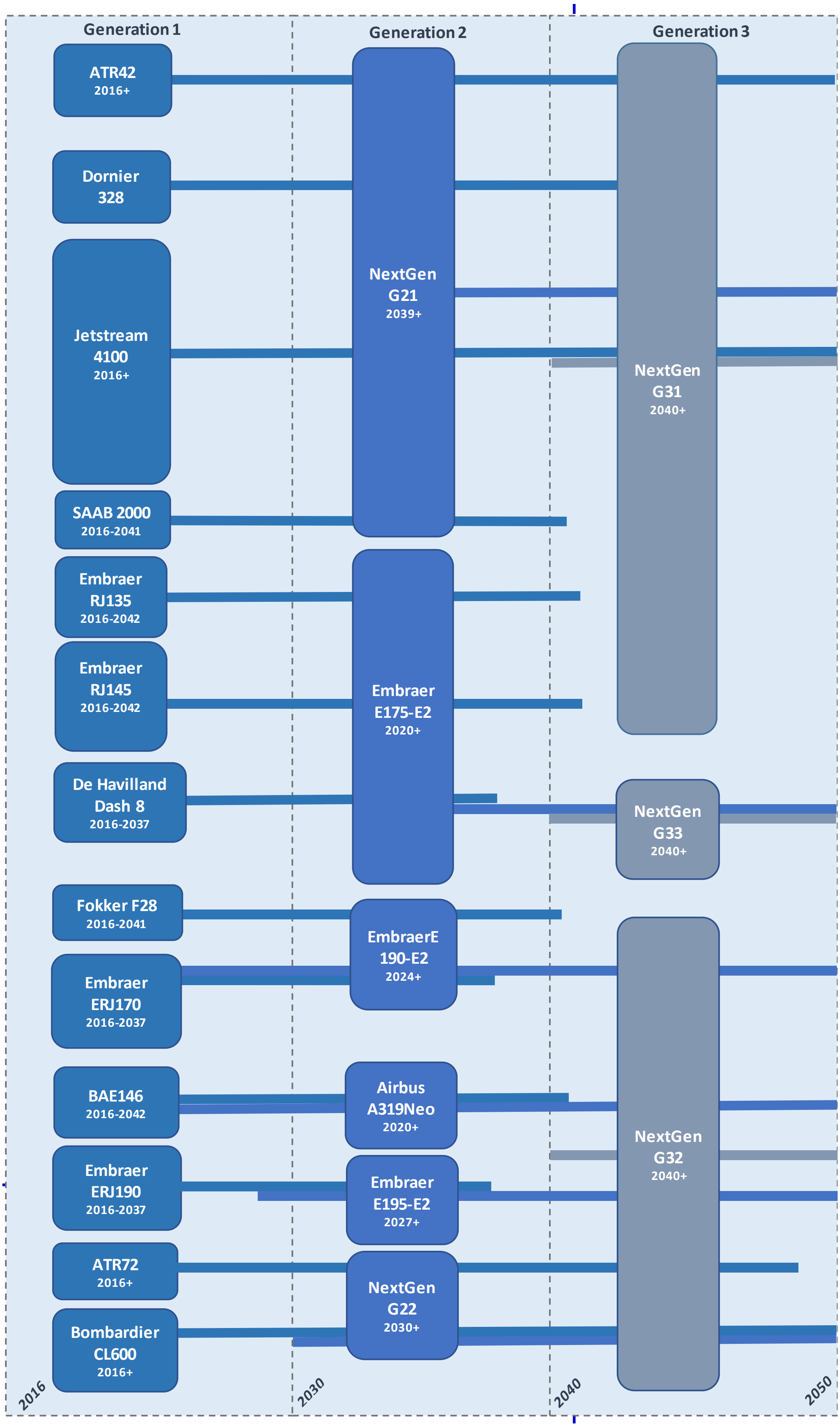
*Note that each supply pool has been developed with reference to the peer review undertaken by Ricardo Energy & Environment
(see DfT aviation fleet mix model: a review - GOV.UK (www.gov.uk)). The only change to this review is to remove existing aircraft types that have ceased significant operation at UK airports since the disruption caused by the COVID-19 pandemic.

Boeing



Generation 1
Generation 2
Generation 3
737-300
2016-2042
737-600
2016-2042
737-400
2016-2019
737-800
2016-2042
737-900
2016-2037
757-200
2016-2042
757-300
2016-2042
767-300
2016-2019
787-900
2016+
747-400
2016-2019
777-200
2016-2042
747-800
2016-2019
777-300ER
2016+
737 MAX 8
2020+
737 MAX 9
2020+
737 MAX 10
2022+
787-800
2016+
777-9X
2020+
787-10
2020+
777-9X
2020+
NextGen
G32
2040+
NextGen
G33
2040+
NextGen
G34
2040+
NextGen
G35
2044+
2016
2030
2040
2050

Others


Generation 1
Generation 2
Generation 3
ATR42
2016+
Dornier
328
Jetstream
4100
2016+
SAAB 2000
2016-2041
Embraer
RJ135
2016-2042
Embraer
RJ145
2016-2042
De Havilland
Dash 8
2016-2037
Fokker F28
2016-2041
Embraer
ERJ170
2016-2037
BAE146
2016-2042
Embraer
ERJ190
2016-2037
ATR72
2016+
Bombardier
CL600
2016+
NextGen
G21
2039+
Embraer
E175-E2
2020+
EmbraerE
190-E2
2024+
Airbus
A319Neo
2020+
Embraer
E195-E2
2027+
NextGen
G22
2030+
NextGen
G31
2040+
NextGen
G33
2040+
NextGen
G32
2040+
2016
2030
2040
2050

* Research suggests that the A319Neo will prove the most common replacement for movements previously made by the BAe146, hence it appears in both Airbus and ‘Other’ supply pool illustrations.

Annex H: Glossary

APD	Air Passenger Duty
ANPS	Airports National Policy Statement
ATM	air transport movement (i.e. a commercial aircraft flight)
BEIS	Department for Business, Energy, Industrial Strategy (UK government)
CCC	Committee on Climate Change (independent government advisory body)
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent – includes and uplift to forecast carbon dioxide to allow for other greenhouse gases methane (CH_4) and nitrous oxide (N_2O) emitted when jet fuel is burnt
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation (ICAO)
EEA	European Environment Agency
ETS	Emissions Trading Scheme
FMM	Fleet Mix Model – conversion of ATM forecasts into specific aircraft types by forecast year allowing for retirement and replacement of the fleet
fuel efficiency	Seat-kms delivered per tonne of aviation fuel
GDHI	Gross Domestic Household Income
GVA	Gross Value Added – a measure of production of goods and services in an area
ICAO	International Civil Aviation Organisation
IMF	International Monetary Fund (economic forecaster)
MBU	'Making Best Use' – current government policy on making best use of the capacity of existing runways with the airport expansion stated in the ANPS
mppa	million passengers per annum (terminal passengers)
NAEI	National Atmospheric Emissions Inventory (of the UK)
NAPAM	National Air Passenger Allocation Model – distributes unconstrained UK passengers around UK airports and competing foreign hubs
NAPDM	National Air Passenger Demand Model – econometric model of unconstrained trip demand by passenger markets
OBR	Office of Budget Responsibility (the independent UK economic forecaster)
OECD	Organisation for Economic Co-operation & Development – but also a long-haul region in NAPDM
ONS	Office of National Statistics (UK)
ped	price elasticity of demand
RoE	Rest of Europe – a short-haul region in NAPDM
RoW	Rest of the World – a long-haul region in NAPDM
SE	Southern Europe – a short-haul region in NAPDM
tankering	practice of taking on board more fuel where lower prices offset the cost of transporting surplus fuel
yed	income demand elasticity