Department for Transport

DfT Aviation Modelling Suite

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Contents

List of Figures

List of Tables

1. Modelling development

Passenger, aircraft and carbon emission forecasting

1.1 The Department for Transport (DfT) relies on an aviation modelling suite to forecast air passengers, aircraft movements and CO_2e emissions at UK airports. The DfT forecasts serve a number of purposes:

- Take a view on a range of expected passenger demand and aircraft movements to inform future aviation strategy and a range of policies.
- Inform decisions on the need for and location of new airport capacity and growth projects and environmental assessments associated with such decisions.
- Provide estimates for the expected range of aviation greenhouse gas emissions to reach our Net Zero target.
- Can be used across other Government departments, their agencies and others working independently within the aviation sector.

1.2 The modelling suite 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.

1.3 The structure of the modelling suite is illustrated in Figure 1-1.

1.4 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 (2019). The latest version is more suitable than its predecessor for use in assessing air passenger demand, air transport movements and carbon emissions from UK aviation.

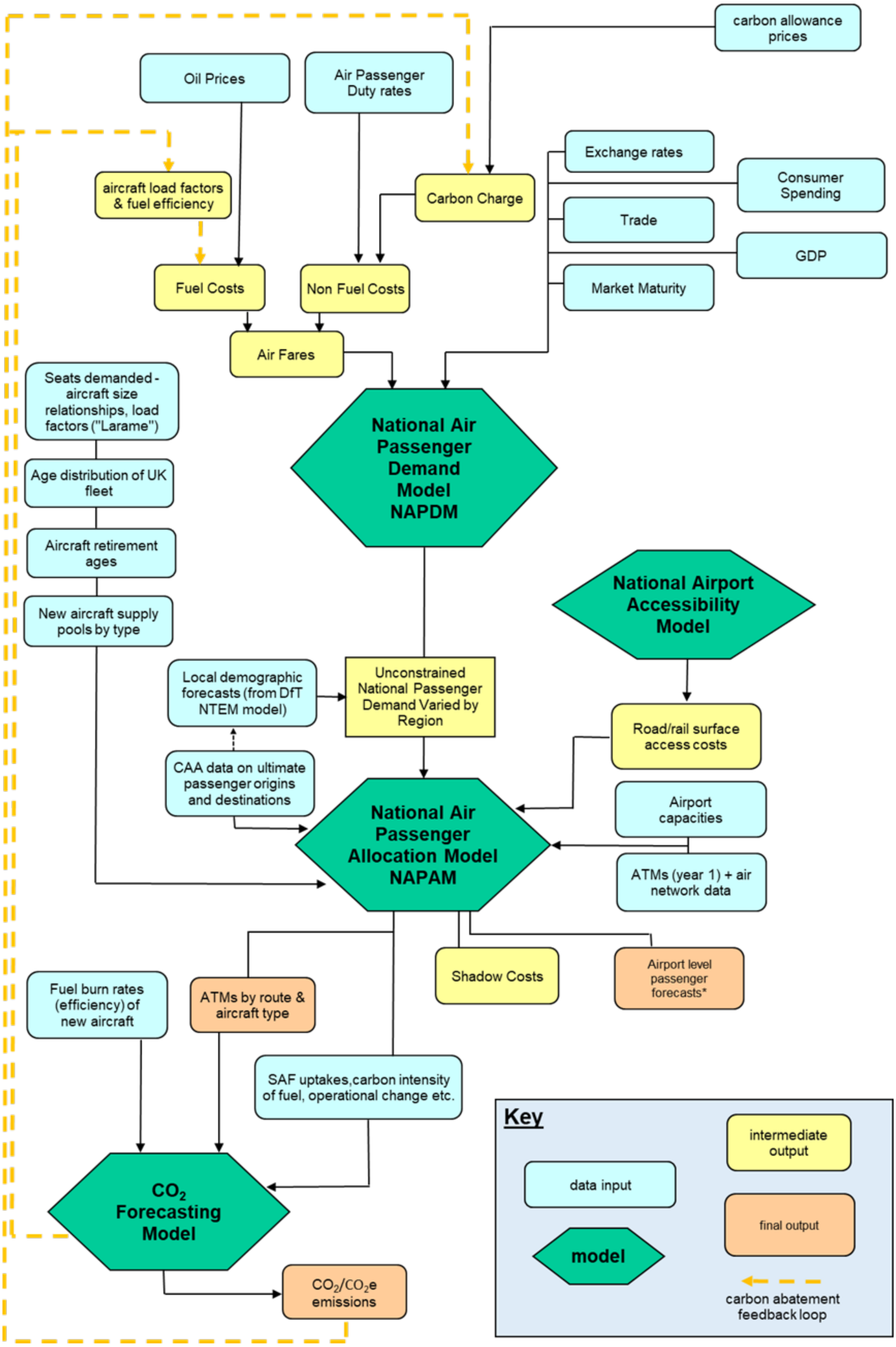

Figure 1-1: Aviation modelling suite

This report

This report is an update to the aviation modelling suite used for the last main forecasts published in 2017.[1] A significant range of updates have been made since then, and many of the updates were outlined in the Jet Zero modelling framework[2] document which accompanied the Jet Zero Strategy. The aim of this document is to present the latest aviation modelling suite, while in relevant sections we will explain the updates since the model versions used for the 2017 aviation forecasts and the Jet Zero Strategy.

Chapter 2 describes the changes made to the National Air Passenger Demand Model (NAPDM). It explains how these impact the national forecasts with reference to the alignment of air fares to new world region geography, the inclusion of SAF uptake and cost in the fare model, overrides to account for COVID-19 pandemic effects on demand and updated economic drivers.

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, and updated airport capacities.

Chapter 4 describes 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 CO_2 model[3] downstream of NAPAM, essentially unchanged from the last model version, but updated to and validated against 2019 CO_2e emissions returns.

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[1] https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

[2] https://www.gov.uk/government/publications/jet-zero-modelling-framework

[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 passenger, aircraft (ATM) and CO_2e 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 terminal passengers at airports, aircraft movements and CO_2e 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 or departing from 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, associated economic activity, and air fares. Income and price elasticities are adjusted over time to take account of market maturity assumptions as shown in Figure 2-1.

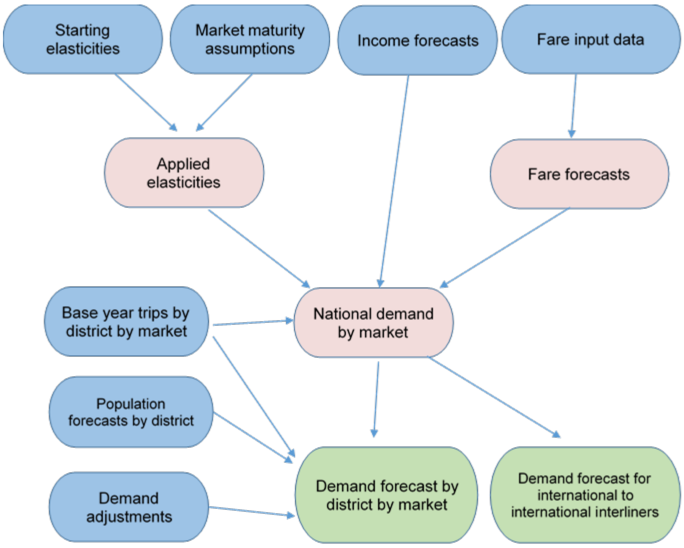

Figure 2-1: NAPDM model structure

2.4 The NAPDM fare forecasts module plays an essential role in the unconstrained passenger trips forecast.

2.5 The fares module breaks future fares down by modelling market into key air fare components including:

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

In most model applications the model process cascades from NAPDM and its macro-economic inputs through the airport and aircraft forecasting elements down to the CO_2 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 CO_2 emissions model and NAPDM demand forecasts.[4] This model feedback relationship is illustrated in Figure 1-1.

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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) chapter 4. The feedback is used to impact the fuel efficiency and load factor inputs to the NAPDM fares per passenger model rather than the carbon price which is an input to the model.

2.6 Since the department's 2017 aviation forecasts document there have been significant updates and improvements to NAPDM, and the following updates fed into the model version used for the Jet Zero Strategy in 2022:

- 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 fitting econometric models and more evenly sized passenger markets. NAPDM units for unconstrained demand is national passenger trips rather than estimates of national terminal passengers.
- 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.
- 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.

In addition, the following refinements are made to NAPDM since 2022 Jet Zero Strategy:

- To align with the world region geography, the starting level of non-fuel costs and average trip length to each region have been recalculated, to better reflect the costs of the current NAPDM world regions (i.e. SE, RoE, OECD, RoW), compared to the old NAPDM geography (i.e. WE, OECD, NIC, LDC).
- The fare model has been updated to reflect the uptake of sustainable aviation fuels (SAF), based on forecasted SAF uptake and prices.
- To account for the effect of COVID-19 pandemic, a demand override is introduced in the early years of the model. This reflects the observed level of demand reduction where observed data is available E.g., 2020-2022. For years beyond this (e.g., 2023), the demand override sets the trajectory for recovery to return to 2019 levels and the point at which long-term demand growth is based on the demand elasticities.

Geographical definition

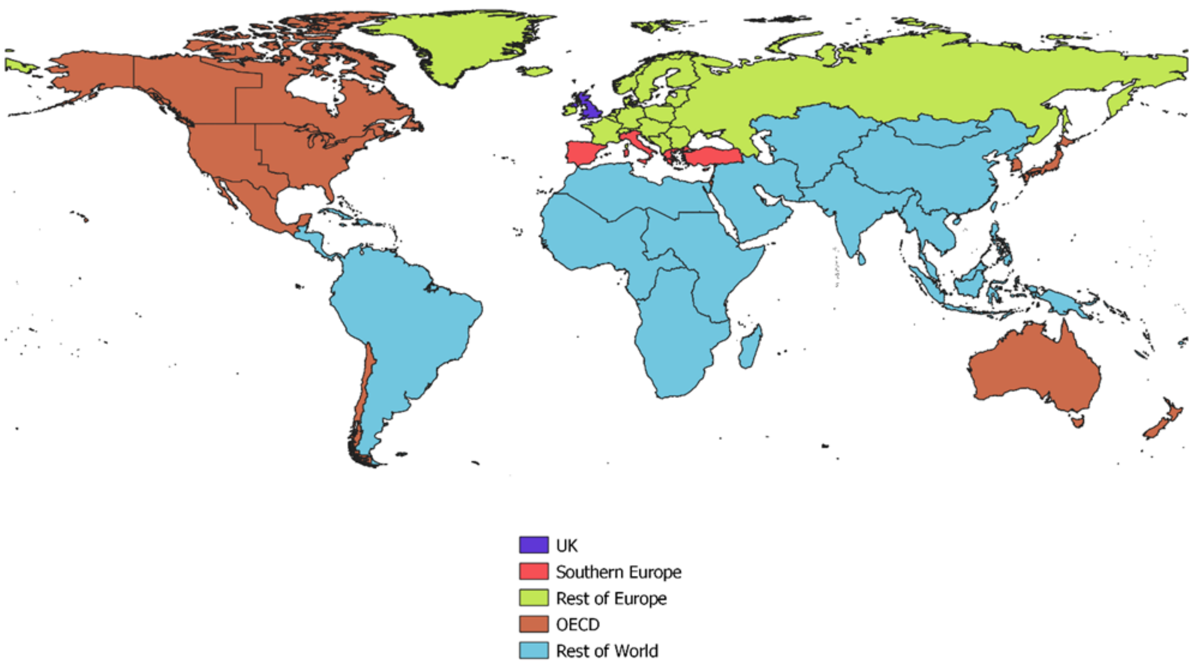

Figure 2-2 : Aviation model world zones and regions

2.7 The 2017 forecasts version of NAPDM 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.

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

2.8 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 as shown in Figure 2-2:

- Southern Europe (SE)
- Rest of Europe (RoE)

- Other OECD countries (OECD)
- Rest of the World (RoW).

2.9 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.

Air passengers by residency and journey purpose

2.10 The department's aviation modelling suite splits passengers by their residency, UK or foreign, and their journey purpose by business or leisure. Business can be more narrowly defined as 'employer's business' as commuting by air is insignificant in terms of air passenger volumes.[5] Leisure includes a wide spectrum of purposes, including 'visiting friends and relatives' (VFR) and holidays.[6]

2.11 The international-international transfer category is not split by journey purpose in NAPDM and is kept separate in this analysis for clarity, but it might be noted that the majority of such passengers are on leisure trips and all are assumed to be foreign residents.[7]

2.12 Domestic passengers for both business and leisure are assumed to be UK residents.[8] This category is for internal UK flights where both the origin and destination are in the UK. Passengers making domestic-international transfers using domestic flights are included in the international markets (e.g. a passenger at Liverpool flying to London and then heading to Southern Europe is counted as an international trip to Southern Europe).

Demand elasticities

2.13 Since 2017, the econometric models have been re-estimated to provide updated demand elasticities. The updated demand elasticities have been used for the Jet Zero Strategy published in 2022. These reflect both the extension of the time series of

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[5] The CAA have produced a study of current business air passenger available at http://publicapps.caa.co.uk/docs/33/CAP796.pdf

[6] More detailed breakdowns of passenger journey purposes is collected in the CAA passenger surveys - see, for example, http://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Consumer-research/Departing-passenger-survey/Departing-passenger-survey

[7] Between 2011-2016 the CAA passenger interview surveys show that 76% of international-international transfers were on leisure journeys.

[8] CAA surveys 2011-2016 suggest around 94% of such flights are made by UK residents.

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.[9] 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.[10] 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 derives demand elasticities separately before and after the structural breaks. Although tests for structural breaks were undertaken when the previous NAPDM models were estimated, no robust evidence was found, probably due to 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.[11]

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[9] 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.

[10] 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.

[11] 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.

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 and a summary is show in Table 2-1.

	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 to provide equivalence with the current geographic definitions.

Table 2-1: NAPDM elasticities

2.15 A full technical account of the updating of NAPDM’s econometric models is in the document associated with Jet Zero Strategy: *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. Table 2-2 below summarises the sources used to project the key drivers of demand in the current model.

2.17 Input GDP and other income related input forecasts include the projected wider impacts of the COVID-19 pandemic and recovery of the UK and world economies. We assume 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 and Consumption Expenditure, Growth Rates	2015-2028	OBR, various years and November 2023
	2029-2050	DfT TAG, May 2023
Foreign GDP Growth Rates	2015-2028	IMF, October 2023
	2029-2050	OECD, October 2021
GDP Deflator Growth Rate	2015-2020	DfT TAG, May 2023
	2021-2027	OBR, March 2023
	2028-2050	Held at 0% by assumption
ETS Carbon Prices	2015-2022	ICE EU ETS and UK ETS clearing price
	2023-2050	DESNZ forecast, November 2023
CORSIA Carbon Prices	2020-2050	DfT analysis based on CAEP ICAO 2021 and BEIS carbon appraisal value 2021
SAF Uptake	2023-2050	Up to 2040, DfT SAF Mandate, 2024
		Post 2040, DfT assumption aligning with Jet Zero Strategy 2022
SAF Prices	2023-2050	Up to 2040, DfT assumption based on SAF Mandate analysis, 2024
		Post 2040, DfT assumption based on same methodology as SAF Mandate analysis
Oil Prices	2015-2050	DESNZ, November 2023
Exchange Rate	2015	ONS, May 2017
	2016	DESNZ, 2016
	2017-2027	OBR, various years
	2028-2050	Held constant by assumption
APD	2015-2023	HMRC, April 2021; Autumn Budget 2021
	2024-2050	Held constant by assumption

Model Input	Period	Source
Load Factors	2015-2050	NAPAM, 2024
Fuel Efficiency	2015-2050	NAPAM, 2024
CO_2e content of fuel (carbon intensity)	2015-2050	DfT CO_2 model, 2024
Population by District, Growth Rates	2015-2050	DfT NTEM v8.1

Table 2-2: NAPDM input data sources

Fare modelling, carbon price and fuel cost

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 Annex B.

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

2.20 The 2017 version of the NAPDM model had applied one carbon price series across all routes. In practice, flights within the UK, from the UK to the European Economic Area (EEA), between the UK and Gibraltar and from Great Britain to Switzerland are in scope of the UK Emissions Trading Scheme (UK ETS), while international flights between participating states are in scope of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

2.21 The NAPDM fares model has been updated to apply different carbon price assumptions to different markets. For modelling purposes, the UK ETS carbon price series has been applied to the Southern Europe (SE) and Rest of Europe (RoE) regions while the CORSIA carbon price series has been applied to OECD and Rest of World (RoW). [12] [13]

2.22 Carbon cost incurred to airlines relates to the carbon intensity of fuel. Different types of fuel emit different levels of carbon, where low carbon energy emits less carbon than conventional kerosene, and airlines would pay less carbon cost if they uptake a higher proportion of low carbon fuel (e.g. SAF). We consider the components of fuel types in our CO2 model estimate the carbon intensity of fuel (i.e. fuel factor).

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[12] Flights from the UK to the EEA and Switzerland are in scope of both the UK ETS and CORSIA. For modelling purposes, the UK ETS carbon price series has been applied to these flights to reflect the higher carbon price airlines currently face on these routes. The government is carefully considering the approach to CORSIA implementation and interaction with the UK ETS, and we will consult further in due course.

[13] The demand module of the aviation modelling suite also applies the carbon values on flights arriving in the UK. It is not able to apply a different series to these flights (e.g. those covered by the EU ETS) so the same carbon price (either UK ETS or CORSIA) is assumed on flights departing and arriving in the UK to/from a specific country/region. This is recognised as a minor limitation to the model. Carbon emissions are only reported on departing flights.

2.23 Fuel costs are another important component in the NAPDM fare model. Airlines incur a cost for fuel in every flight, and these costs are passed on to passengers, reflected in air fares. Air fares are higher when fuel prices are higher.

2.24 The 2017 version of the NAPDM, and the version used for Jet Zero Strategy, applied one series of aviation fuel prices, linked to crude oil prices. However, airlines started to adopt sustainable aviation fuel (SAF) from around 2020. In addition, the government is introducing a mandate on SAF to take effect from 2025.

2.25 Therefore, the fares model has been updated to reflect the uptake of SAF, based on the SAF mandate uptake trajectory and forecasted SAF prices. The effects on NAPDM are twofold. Firstly, SAF prices are higher than traditional aviation jet fuel prices, and the fuel costs are now a weighted average of both types of fuel, depending on the uptake percentage of SAF. Secondly, an airline does not need to pay a carbon price when SAF is used, so the fare model removes the carbon cost for the percentage of SAF uptake.[14]

Distribution of national demand around the UK regions

2.26 NAPDM has a function to manage the disaggregation of the growth in demand to the 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. Changes in the local district composition of demand were driven by projected local population changes.[15] Districts with faster forecast population growth received a higher share of each market's forecast demand growth.

2.27 This approach has been used in 2017 forecast and in Jet Zero Strategy in 2022, and we have reviewed it since the 2017 forecasts. Some stakeholders, such as airport operators in the north of England, had raised concerns that this approach

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[14] Both CORSIA and UK ETS reduce obligations to operators which purchase SAF so the fare model removes the carbon cost. Under UK ETS this is according to the percentage of SAF uptake and under CORSIA relative to the lifecycle emissions savings of their SAF over fossil kerosene.

[15] The population projections for the period 2016-2061 for mainland UK were taken from the department's Tempro 8.1 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.

disproportionately allocated demand to London and the southeast, at the expense of northern regions.[16]

2.28 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 justifies retaining the use of independent (ONS) forecasts of population growth as the sole driver of regional variation in propensity to fly.

2.29 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.[17]

2.30 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 difficult to predict over the longer term. Overall, the review 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 NAPDM baseline distribution of future demand around the regions.[18]

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[16] However, it should be noted that after a brief period, 2016-2017, 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 pandemic affected year of 2020.

[17] 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.

[18] 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 limited reason in applying local overrides in the context of some policies such as Jet Zero as any impact on national CO_2e emissions totals would be minimal.

Market maturity

2.31 The econometrics is supplemented by a number of assumptions relating to 'market maturity'. This term is often used to refer to the process by which the demand for a product becomes less responsive to its key drivers through time. Air travel demand has shown very strong growth for several decades and while it would seem reasonable to start from the premise that the drivers of demand in the past will continue to drive demand in a similar way in the future, this can only be the starting point. Any exercise to forecast the future must also consider how the relationships observed in the past might change in the future.

2.32 NAPDM allows the modelling of market maturity that income elasticities will gradually decline over time as the aviation market matures. This is because we expect there is some product cycle in aviation – early demand gives way to steady growth:

- Growth slows as consumers become more familiar with product.
- As number of flights increase, people are less likely to respond to increases in income by increasing air travel.

2.33 NAPDM assumes that the income elasticities decline linearly, starting from estimate values in econometric models to no more than 0.55 by the end of maturity process, which is assumed to start in 2025 and end by 2095. When a starting elasticity is already below 0.55, the elasticity is unchanged throughout the modelled period.

3. National air passenger allocation model (NAPAM)

Introduction

3.1 The National Air Passenger Allocation Model (NAPAM) forecasts passenger demand at 29 airports throughout the UK and four competing overseas hubs. NAPAM takes national forecasts of the underlying demand for air passengers to, from and within the UK from the national NAPDM forecast.

3.2 It forecasts how passengers might choose between the airports in reaction to their relative estimated attractiveness now and in the future. This choice takes account of airport capacity, surface journey accessibility, flight time, differentials in average annual fare and levels of air services.

3.3 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 aircraft types for each route are forecast for use downstream in the CO_2 emissions modelling.

3.4 Since the 2017 aviation forecasts[19] a comprehensive range of software improvements and updates to key input data have been completed, many of which have been operational for the 2022 Jet Zero Strategy[20] as outlined in the Jet Zero modelling framework document.[21]

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[19] UK aviation forecasts 2017 - https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

[20] Jet Zero Strategy: delivering net zero aviation by 2050 - https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050

[21] Jet Zero: modelling framework - https://www.gov.uk/government/publications/jet-zero-modelling-framework

3.5 Changes from 2017 aviation forecasts to 2022 Jet Zero Strategy are:

- greater geographic detail and compatibility with NAPDM forecasting regions
- Updated model validation of performance against 2019 actuals on passengers, aircraft and emissions at UK airports
- updating of the airport capacity assumptions used for aviation emissions modelling to better reflect recent airport planning applications or specific proposals published by UK airports since 2018
- improved model convergence through better 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.
- 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,
- General upgrade in model performance and an improved range of outputs.

3.6 A further series of updates in the 2024 version of NAPAM have allowed the following to be incorporated:

- Partial removal of airline type split of Scheduled, Charter, Low-cost (SCL)

- Updates to the passenger to airport choice model variables, coefficients, model forms and frequency function

- New values of time for aviation modelling purposes

- New version of National Airport Accessibility Model (NAAM2) for surface journey accessibility

Airports modelled in NAPAM

3.7 NAPAM models the busier mainland UK airports which had some regular international commercial passenger air services operating in 2019. As described later in this chapter, the airports are modelled as constrained by their assumed annual runway capacities or, in some cases, by annual terminal capacities. Forecasts are still made at the "route" level where a route is defined as one of the 29 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.

3.8 The representation of Belfast International and Belfast City airports is also modelled by surface ground origins of their passengers and their airport access in the same manner as the mainland UK airports.

3.9 Table 3-1 shows the airports in the model (with IATA codes) arranged by region.

London	South West and Wales	Scotland
Gatwick (LGW)	Bournemouth (BOH)	Aberdeen (ABZ)
Heathrow (LHR)	Bristol (BRS)	Edinburgh (EDI)
London City (LCY)	Cardiff (CWL)	Glasgow (GLA)
Luton (LTN)	Exeter (EXT)	Inverness (INV)
Stansted (STN)	Newquay (NQY)	Prestwick (PIK)

South East and East	Northern Ireland	Midlands
Southampton (SOU)	Belfast City (BHD)	Birmingham (BHX)
Southend (SEN)	Belfast International (BFS)	East Midlands (EMA)
Norwich (NWI)		

North	Overseas hubs
Doncaster-Sheffield (DSA)[22]	Amsterdam Schiphol (AMS)
Durham Tees Valley (MME)	Dubai (DXB)
Humberside (HUY)	Frankfurt (FRA)
Leeds-Bradford (LBA)	Paris Charles de Gaulle (CDG)
Liverpool (LPL)	
Manchester (MAN)	
Newcastle (NCL)	

Table 3-1: Airports in DfT aviation model

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[22] In November 2022, passenger services ceased at Doncaster Sheffield Airport. The airport is included in the model but with zero capacity, effectively closing the airport to passenger traffic in our forecasts. Treating Doncaster Sheffield Airport in this way is not a prejudgement of the future of Doncaster Sheffield Airport. The decision to include Doncaster Sheffield Airport with zero capacity reflects the airports status at the time of writing.

Geographical definition

3.10 The Great Britain geography is split into 455 district-based ground origins and remains unchanged from the 2017 forecasts document as shown in Figure 3-1.

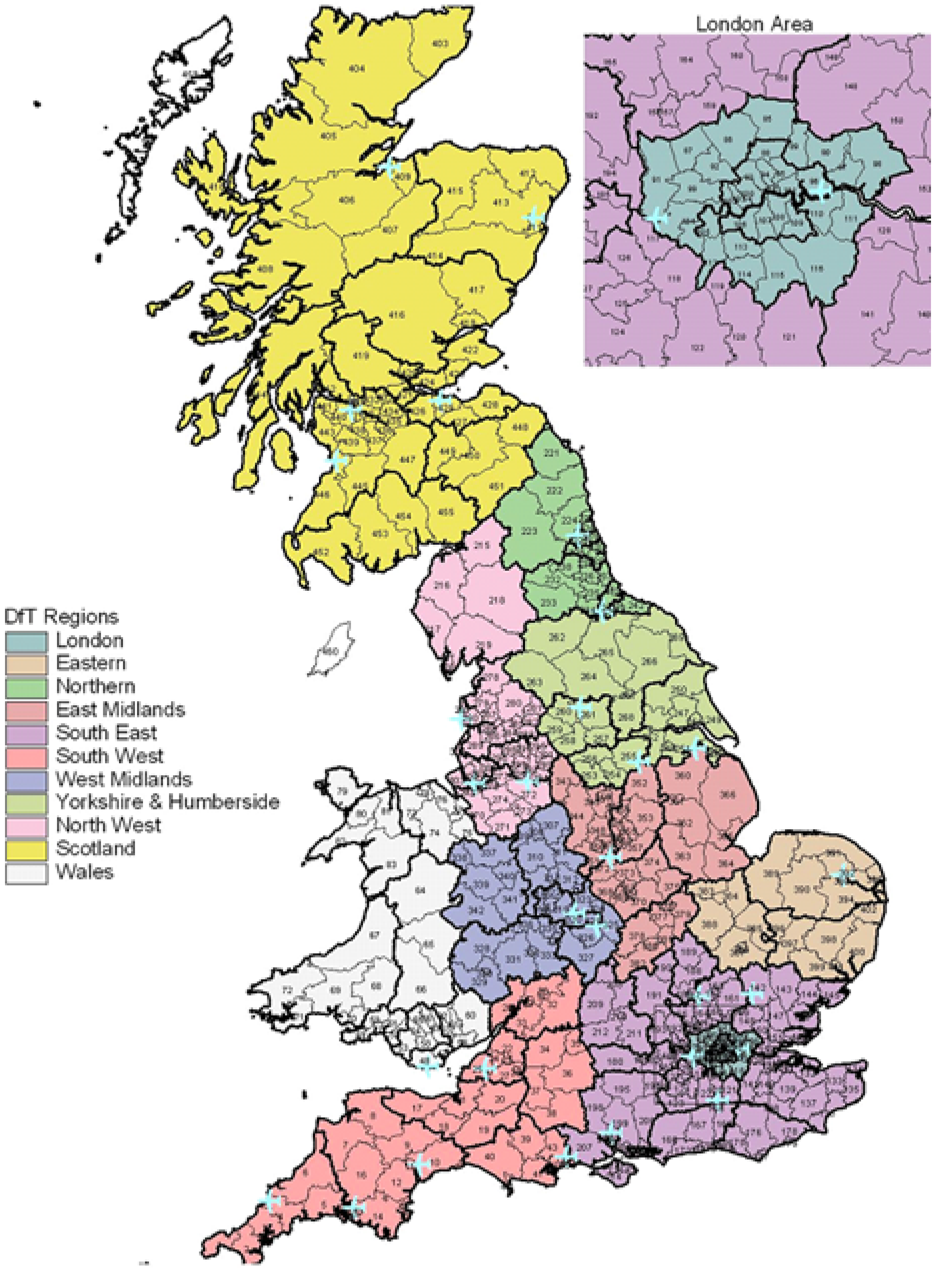

Figure 3-1: Great Britain district zones

3.11 The zoning follows 1991 census geography rather than current administrative boundaries. This is deliberate to retain sufficient granularity in regions such as Scotland, Durham, Northumberland, Shropshire and Wiltshire where current unitary administrative boundaries are too broad to allow accurate passenger allocation between neighbouring airports.

3.12 The modelling treatment of Northern Ireland incorporates 37 zones on the island of Ireland and are modelled in the same way as the mainland UK airports. This means that the two Belfast airports will no longer be modelling "add-ins" and locally this provides more responsive and consistent passenger allocation and ATM modelling.

3.13 International passengers are defined as those that travel to one of the 67 international zones as their ultimate destination. There are 42 international route group zones and 25 separate zones representing the largest European airports. The model explicitly includes the option for passengers to transfer at a hub airport either in the UK or abroad, including Amsterdam, Frankfurt, Dubai or Paris. These are illustrated in Figure 2-2 presented earlier in this report in Chapter 2 and listed in Annex C.

3.14 The international geography has been substantially revised and modernised since the 2017 forecasts as they had not been changed since the model was first developed. This has resulted in an increase of international zones and further details of 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.
    - 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 C).
- **Improved precision in the passenger allocation ATM and CO_2 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 CO_2e emissions modelling benefits from all the above.

3.15 The 42 ‘route group zones’ are each further subdivided into up to 30 possible destinations.

Surface Access

3.16 The surface access journey costs from each district (zone) to each airport in the model are a key part of predicting future airport usage. Passengers, when choosing their preferred airport within NAPAM, take into account the time and money costs of accessing each airport. The detailed road and rail transport networks used to extract travel costs connecting all zones to all to airports are integrated into the department's aviation modelling suite through the National Airport Accessibility Model (NAAM2).

3.17 The most significant development relating to surface access have been:

- Newly created zones for modelling surface access to airports in Northern Ireland
- Further disaggregation of England, Wales, Scotland zones into smaller zones based on MSOA zones (over 8000).
- Update of the road network based on DfT NTM (2018) network journey time and distance matrices and validation against 2018 Traffic Master data
- Update to the 2019 rail timetable services and validation against TfL data and DfT Moira model.
- Update to the HS2 network to only include phase 1

3.18 The updates allow for a better representation of how passengers access both the road and rail networks as shown in Figure 3-2.

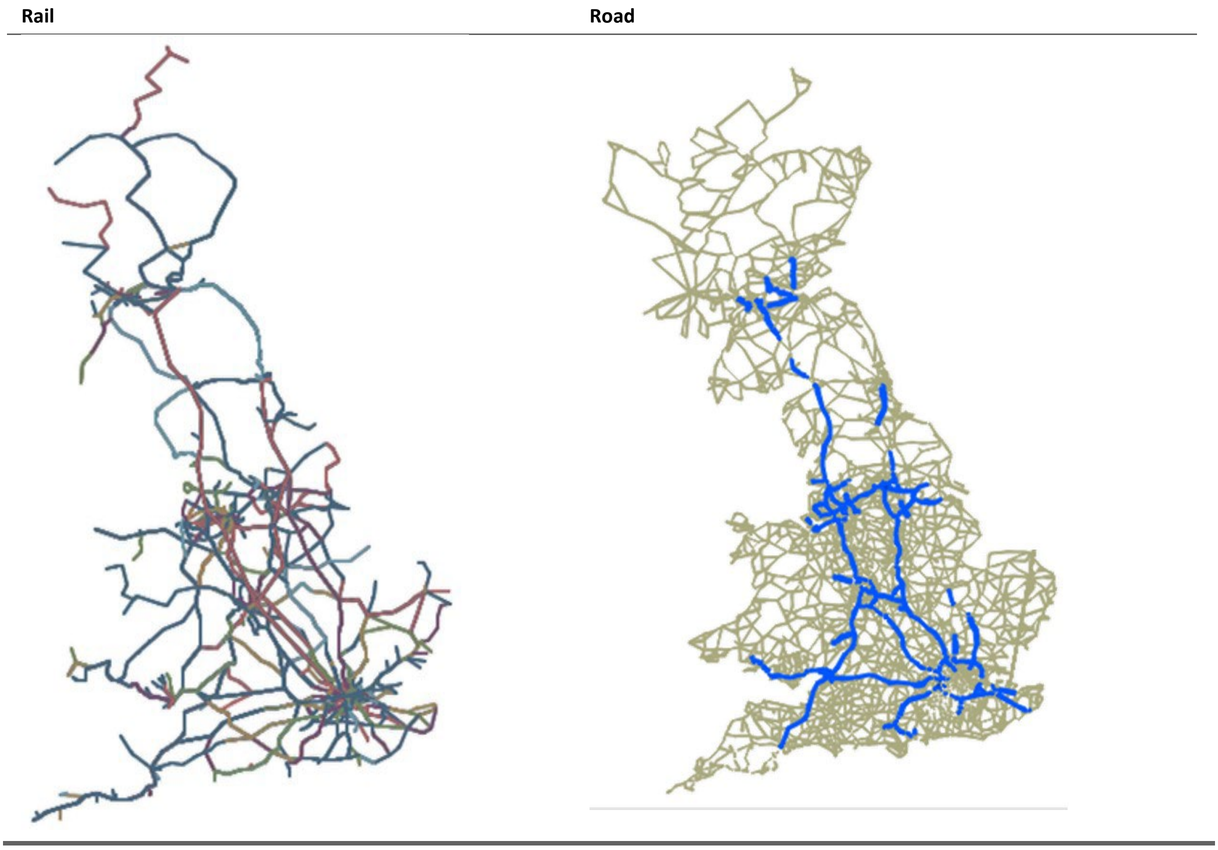

Figure 3-2: NAAM2 rail and road networks

3.19 The estimated time and money costs of accessing airports by road or rail help to determine passenger airport choice is combined into a single cost input and monetised using a value of time. The value of time has been determined by DfT in a study conducted in 2019 on aviation modelling values of time. The basis of this study was the 2015 DfT surface mode value of travel time studies with adjustments made to reflect the characteristics of aviation passengers. The adjustments centre around the average income of air passengers being higher than those using equivalent surface access modes and thus the trade off between time and money would vary for aviation passengers.

3.20 The input is updated each year reflecting growth factors in modelling values of time rail fares and road costs as described in DfT TAG.[23]The values of time used in the latest version of the model compared to 2017 forecasts is shown below in Table 3-2.[24] The update values are lower than previously used in aviation forecasts and are more comparable with equivalent surface mode values.

	2017 £/hour (2015 prices)	**2024 £/hour (2015 prices)**
Business	£47.17	£26.63
Leisure	£11.12	£7.41

Table 3-2: Value of time

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[23] DfT TAG data book from May 2023 https://www.gov.uk/government/publications/tag-data-book

[24] Note the 2017 forecasts had separate values of time for each market and only the average is shown here for comparison purposes

Modelling the passenger's choice of airport

3.21 The NAPAM has been built to explain and reproduce passengers' current choice of airport, as recorded in CAA passenger interview surveys.

3.22 A passenger flight is usually one part of a journey, comprising several stages and modes, between different parts of the world. To understand how passengers choose between UK airports it is therefore necessary to consider not just the airports they are flying between, but the initial origin or ultimate destination of their journey in the UK. For example, a passenger leaving Gatwick airport might have an initial origin at their home in Kent, and a passenger arriving at Leeds-Bradford airport might have a destination in York.

3.23 A traveller's choice of airport could therefore be determined by several factors, including:

- the initial origin (for outbound) or ultimate destination (for inbound) in the UK of their trip
- the final destination in the UK or overseas
- the location of airports in the UK
- the availability of flights offered at each airport
- the possibilities of transferring and making onward connections at UK and overseas airports
- the travel time and other costs for accessing each airport by road and public transport
- the traveller's preference for services offered at each airport and their value of time

3.24 The inclusion and strength of each factor in driving an airport's share of demand is determined by estimating logit model choice parameters with data on passenger airport choices drawn from CAA passenger interview surveys.[25] This involves using statistical techniques to determine which factors and the magnitude of their relative weighting to maximise the model's accuracy in predicting current choices (see text box below). This means that the model aims to represent passengers' actual, observed, airport choice behaviour.

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[25] Passengers are interviewed by the CAA at Heathrow, Gatwick, Stansted, Luton and Manchester every year with all but the smallest regional airports in the model being rotated on an annual basis normally on a 3-5 year cycle.

3.25 The current logit model choice parameters were re-estimated using a dataset derived from 2015 CAA survey data.[26]

Allocating passengers between airports

Modelling and forecasting how people choose between a set of discrete options is an established practice in statistics and transport modelling. NAPAM contains an application of the standard multinomial logit formulation commonly used in this context. The model estimates the proportion P of passengers with journey purpose p travelling to/from UK zone i to foreign destination j, that use airport A, can be represented by the following flexible functional form (the example is the simplest form):

$$P_{(i,j,A,p)} = \frac{e^{-\beta_1 \times Cost_{(i,j,A)}}}{\sum_{R \in all\ available\ Routes} e^{-\beta_1 \times Cost_{(i,j,R)}}}$$

where
i = zone of origin
j = zone of destination
p = journey purpose
A = airport
R = route
Cost(i,j,A) = generalised cost of travelling from zone i to zone j using airport A
β = parameter to be estimated during calibration

The process of model calibration involves using statistical data to select the set of values for the unknown parameters which lead to the model's predictions best fitting the data.

The strength of different drivers of passengers' airport choice is likely to vary between passenger groups – for example, business passengers may be more affected by the frequency of flights offered. Therefore, separate allocation models are estimated for each market.

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[26] 2015 survey data was complemented by including observations compatible from 2011-2014 to increase the sample size.

Estimation of new logit model choice parameters

3.26 A peer review of NAPAM in 2010 made some specific recommendations relating to the airport logit choice model that warranted further investigation, that DfT have considered. Specifically, nesting of the domestic choice and reviewing the frequency variable were priority items.

3.27 Taking into account the recommendations of this review and feedback from stakeholders, the following key model characteristics were investigated:

- Review the 3 international market destination zones of short haul, US and long haul and test whether 4 international market destination zones consistent with NAPDM could be utilised (SE, RoE, OECD, RoW[27]).
- Consider relaxing the waiting time interpretation of the frequency[28]
- Consider using logarithmic form of variables instead of linear for the frequency function
- Consider nesting of alternatives in the international and domestic market
- Review the surface access variable for balance between highway and rail costs
- Removing value of time (except in surface access costs)[29]
- Consider the additional variables that explain passengers' choice e.g.
  - Air fare
  - Airport preference
  - Airline preference
  - Direct/indirect routing preference

3.28 The logit model choice parameters were estimated using a dataset derived from 2015 CAA survey data[30] and combined with other observations or estimates as shown in Table 3-3

Data	**Source**
Route taken (origin, previous, departure, next and final airport)	CAA survey data
Journey purpose	CAA survey data
Passenger type	CAA survey data

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[27] Southern Europe (SE), Rest of Europe (ROE), OECD excluding Europe (OECD) and Rest of the World (RoW)

[28] The waiting time interpretation is considered to be less useful in the aviation context as the variation between several flights a day and 1 flight a week does not mean that your wait time will vary around half the time interval between consecutive services like it might do on other transport modes.

[29] Previous logit model choice parameters would monetise all parts of the journey e.g., 1 hour of flight time would cost £47 and the co-efficient of the flight time parameter would be applied to a monetized set of flight times. In practical terms this just means that the co-efficient of the parameter loosely changes by a factor equivalent to the value of time and it is possible to estimate a co-efficient for flight time based in minutes and apply to flight time input data in minutes.

[30] 2015 survey data was complemented by including observations compatible from 2011-2014 to increase the sample size. This resulted in coverage increasing from the 11 airports surveyed in 2015 to a total of 19 airports and increase the sample size around 5-fold.

Data	Source
Ground origin	CAA survey data
Airline	CAA survey data
Frequency of flights (UK airports)	CAA airport ATM statistics for aircraft movements[31]
Frequency of flights (Foreign Hub airports)	OAG ATM route data
In flight time (observed)	CIRIUM flight schedules[32]
In flight time (modelled) [33]	DfT flight time model
Fares [34]	DfT aviation fares model
Surface access costs	DfT NAAM model
Domestic road demand	DfT NTM model

Table 3-3: Data sources for estimating model choice parameters

3.29 The estimation of logit model choice parameters has successfully completed without the requirement for variables to be monetised using value of time and showed that the share of travellers originating in, or destined for, each zone potentially travelling via each of the up to 29 modelled airports depends on:

- the **time and money costs of accessing that airport** by road or public transport based on the network of road and rail services (illustrated in Figure 3-2); this uses the standard transport modelling approach of combining journey time, including waiting and interchanging, and money costs into a single 'generalised cost' measure using travellers' value of time (which varies by journey purpose).
- **Frequency** of the service at each airport
- **Flight duration** or average annual **fare** of the service at each airport

3.30 Air fares are an important part of forecasting aviation growth in the national demand model (NAPDM). Air fares also have an additional impact on aviation passengers in determining the choice of airport (as a proxy for airline). Previous attempts concluded air fare to be a statistically insignificant determinant of airport choice when considering average annual fares. During this recent estimation process this was revisited, and air fares were found to be statistically significant in airport choice. It should be noted that this not been possible for all markets and the relative strength compared to other variables is low.

3.31 This is partly attributable to the difficulty in deriving reliable average annual fares with the increasingly wide spread of fares for each route available with web-based ticketing and modern yield management systems. It is also likely to be because the variability of

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[31] aggregated by year, route, and airline for UK departures

[32] Previously known as Innovata, a provider of travel related data and in association with IATA, it provides the Schedule Reference Service (SRS), a database of 99% of all flight schedules worldwide.

[33] Only used where there is no observed data

[34] Average annualised fare model created by DfT based on distance flown from IPS, PaxIS and CAA survey data.

the aggregated fares data between different airports in the same market is often low and taking an average could be masking the actual impact on passengers' choice.

3.32 E.g., at the personal level, at particular times and for particular journeys, it is to be expected that comparison of fares plays a key part in individual choices of airport (especially for those which are geographically close), even though statistically robust relationships cannot be derived for the whole market.

3.33 The estimation process concluded that there was very little difference between the international destination zones of SH, LH, US and zones aligned with NAPAM of SE, RoW, OECD and RoW, therefore these have been updated in NAPAM to be consistent with NAPDM.

3.34 The frequency variable was successfully estimated using a logarithmic function based on the frequency (or minimum frequency for indirect flights) plus an element of waiting time and inconvenience for indirect flights. This was found to perform better in all markets than the previous frequency function and removed the complication of estimating the dampening factor for the previous waiting time interpretation.

3.35 Airline type was investigated and was found to have negligible impact on the performance of logit choice models. The airline type has therefore been removed from this part of the model and is no longer treated separately when it comes to the strengths or types of the variables that determine airport choice.

3.36 For the domestic market the estimation process was successfully able to produce a model that nested the choice of whether to travel by air/surface before looking at the airport that is chosen as shown below in Figure 3-3.

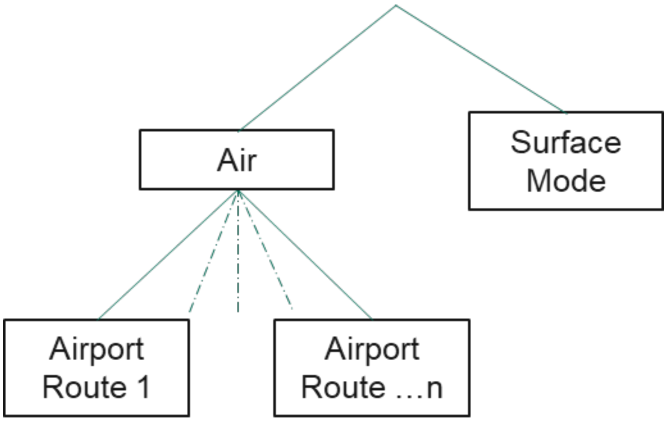

Figure 3-3: Domestic nested choice model

3.37 Other investigations during the estimation process that resulted in no changes are listed below. It should be noted that this is not because they are not deemed part of a passenger’s choice of airport but simply that a statistically significant relationship could not be found with the data available.[35]

- Nesting choices in the international market (e.g., direct/indirect, short/long haul) does not produce better airport choice
- Adjusting the surface access variable for balance between highway and rail costs (including trying to estimate from the data) does not produce better airport choice
- Adding airport preference or dislike (e.g., due to facilities, ease of security etc that an individual might value) does not produce better airport choice

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[35] This could be for a number of reasons such as quality, coverage and availability of the data or because the level of variability between choices does not show enough variance when you take an annual average that is consistent with how NAPAM operated as an annual average model.

Airline market split

3.38 A key stage in the forecasting process is to identify if there are distinct markets within which passenger demand can be expected to differ. In line with previous forecasts, passengers and airline markets are split between scheduled, low-cost carrier[36] and charter flights. Within these markets, passengers are also split by their journey purpose and residency in the same way as they are in NAPDM.

3.39 Charter is defined as a separate category in the forecasts for compatibility with CAA statistical reporting. Charter is primarily package holiday traffic on flights not operating to a regular published schedule. For the purposes of further analysis, it is reasonable to treat charter passengers as part of the UK leisure market, as around 97% of charter passengers fall into this category.[37]

3.40 This split has been reviewed in light of the new data and evidence of convergence of the airline market. The airline market split is considered to useful for two specific reasons to differentiate between scheduled and low-cost airlines. 1) aircraft fleets still differ 2) treatment of transfer passengers still differ and is therefore retained in NAPAM. Charter is also kept as a separate category as there are also benefits in treating their airline fleets separately.

3.41 However, the logit choice model parameters have shown that there is no difference between the markets when considering variables that affect airport choice, e.g., frequency, fare, flight time and costs of getting go the airport. Therefore, the airline market split has been removed in the logit model choice parameters.

3.42 NAPAM is in effect adding airline type of Scheduled, Low-cost carrier and Charter to the 16 international markets from NAPDM of journey purpose and destination zone[38] to further divide the market into different segments as follows:

- Charter – divided into 4 destination regions SE, RoE, OECD, RoW **(4 markets)**
- Scheduled – divided into 4 residency and purpose of UK Business, UK Leisure, Foreign Business, Foreign Leisure and 4 destination regions SE, RoE, OECD, RoW **(16 markets)**
- Low-cost carrier – divided into 4 residency and purpose of UK Business, UK Leisure, Foreign Business, Foreign Leisure and divided into 2 destination regions SE, RoE **(8 markets)**

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[36] The DfT definition of low-cost carrier continues to be restricted to easyJet, Jet2, Ryanair and Thomsonfly. This is significant as the scheduled sector in terms of this split is increased by airlines such as Wizz and Norwegian who are often considered LCCs.

[37] Based on observation in CAA surveys 2011-2016.

[38] Southern Europe (SE), Rest of Europe (ROE), OECD excluding Europe (OECD) and Rest of the World (RoW)

3.43 There are also 2 markets for domestic divided into purpose of Business and Leisure and one for international – International transfer markets that transfer directly from NAPAM. This results in a total of 31 markets as shown in Table 3-4

	Airline	Residency	Purpose	Zone
1	Scheduled	UK	Business	SE
2	Scheduled	UK	Business	RoE
3	Scheduled	UK	Business	OECD
4	Scheduled	UK	Business	RoW
5	Scheduled	UK	Leisure	SE
6	Scheduled	UK	Leisure	RoE
7	Scheduled	UK	Leisure	OECD
8	Scheduled	UK	Leisure	RoW
9	Scheduled	Foreign	Business	SE
10	Scheduled	Foreign	Business	RoE
11	Scheduled	Foreign	Business	OECD
12	Scheduled	Foreign	Business	RoW
13	Scheduled	Foreign	Leisure	SE
14	Scheduled	Foreign	Leisure	RoE
15	Scheduled	Foreign	Leisure	OECD
16	Scheduled	Foreign	Leisure	RoW
17	Low-Cost	UK	Business	SE
18	Low-Cost	UK	Business	RoE
19	Low-Cost	UK	Leisure	SE
20	Low-Cost	UK	Leisure	RoE
21	Low-Cost	Foreign	Business	SE
22	Low-Cost	Foreign	Business	RoE
23	Low-Cost	Foreign	Leisure	SE
24	Low-Cost	Foreign	Leisure	RoE
25	Charter	-	-	SE
26	Charter	-	-	RoE
27	Charter	-	-	OECD
28	Charter	-	-	RoW
29	Domestic	-	Business	-
30	Domestic	-	Leisure	-
31	-	International – International	-	-

Table 3-4: Markets in NAPAM

UK Airport capacities

3.44 The following underlying principles apply to airport capacity modelling used in the department's updated modelling suite:

- all airports must have 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 reflect those set by local planning consents or planning proposals.
- terminal (passenger) capacity constraints are now only used where a current planning restriction is in place.
- in most cases where terminal capacity is not available, effective passenger capacity assumptions in any year are calculated in the model as passenger aircraft movements multiplied by the average modelled aircraft load for that airport in that year.

3.45 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 airports in the UK, for NAPAM to operate.

3.46 Further details on specific assumptions are provided in Annex D: Airport capacity assumptions.

3.47 There have been significant model improvements in 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.

- 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 change the balance between runway and terminal usage at constrained airports relative to our previous forecasts.
- 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.[39] The

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[39] 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.

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.

3.48 As a result of these changes the tolerances around the input capacities are now much smaller 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 proposed new third runway.

Modelling ATMs

3.49 The ATM model forecasts the number of ATMs by aircraft size and route for each airport. It is important to understand the demand in terms of numbers of aircraft flights (ATMs) as well as the number passengers for four reasons:

- A key determinant of passenger choices is the frequency of service provided at different airport options. As such the projection of the number of flights influences passenger decisions.
- As demand is forecast to grow, forecast demand exceeds capacity at some airports. The limiting capacity could be the airport terminal, runway, or a planning constraint. Runway capacity is measured not by passenger numbers, but by the number of ATMs. The ATM model within NAPAM translates passenger demand into ATM demand at each airport, to allow comparison of demand with both passenger and ATM capacity constraints.
- It is important to predict when new routes will become available at particular airports, creating a new option for passengers to consider.
- Finally, predictions of ATMs and aircraft-kilometres by aircraft type on each route are required for estimating future aviation carbon emissions.

3.50 The ATM model in NAPAM simulates the introduction of new routes by testing in each forecast year whether sufficient demand exists to make new routes viable from each airport. Effectively this assumes that supply of routes will respond to demand, subject to airport capacity and a minimum passenger threshold to make a new route commercially viable. The test is two-way, so routes can be both opened and withdrawn year by year. Airports are tested jointly for new routes, allowing them to compete with each other.

3.51 For each route from each airport, the ATM model in NAPAM then forecasts the size of aircraft, load factor, and frequency of operation used to meet forecast passenger demand based on relationships between these factors derived statistically from historical data.

3.52 Forecasts of CO_2e emissions and environmental assessments require more detailed assumptions to be made about the specific aircraft types that make up the stock of aircraft in each forecast year and are discussed further in Chapter 5.

3.53 Freight is not modelled in detail. An assumption about the number of freighter ATMs is nevertheless required in the model as freighters potentially affect the space for passenger ATMs available where capacity constraints exist. At the airport level the number of freighter movements has been volatile with some evidence of overall national decline in recent decades. In the absence of clear trends for individual airports, the modelling now assumes that the number of such movements will remain unchanged from 2019 levels at airport level across the system.

Shadow costs and constraining passengers and ATMs to airport capacity

3.54 NAPAM forecasts both passenger and ATM demand at each airport with ATM demand being a function of passenger demand, load factors and the modelled size of the aircraft on individual routes. Aircraft sizes in seats and load factors evolve over time in the forecasts based on historical evidence from observations.

3.55 The demand allocation components of NAPAM iteratively model the impact and interactions of capacity constraints on the numbers of air passengers, ATM numbers and their passenger loads at each UK airport. Where unconstrained passenger demand wanting to use an airport exceeds capacity, the demand reallocation process increases the cost of using the airport until its demand falls to within its maximum capacity. This cost is known as a ‘shadow cost’, or ‘congestion premium’ and performs the function of limiting the number of passengers to capacity.

3.56 One of two types of shadow cost may be applied when an airport becomes congested. It may be a runway shadow cost, representing a charge per aircraft, which is shared between all the passengers, with its value depending on the average aircraft size for each route in a given year. Alternatively, a terminal shadow cost represents a charge levied equally on every passenger passing through the airport and does not vary by route. Shadow costs can also be seen as representing the value a marginal passenger would place on flying to/from that airport, if extra capacity were available. It is therefore a key input to the appraisal of potential additional capacity.

3.57 The passenger’s value of time is a key component in the impact the shadow cost has on the subsequent choices made. The inherent value of time used for shadow costs in the aviation model comes from the same value of time used in the surface access to airport component. i.e., the value of time is lower in the latest version of the model and therefore the monetised component of shadow costs is lower. This has the effect of dampening the strength of the frequency variable in the passenger’s choice of airport.

3.58 In the iterative demand reallocation process, the shadow cost is added to the other costs of using each over-capacity airport, before repeating the passenger allocation element. When a shadow cost solution is found which fits all airports within user specified bounds of their input runway and terminal capacities, the ATM models are re-calculated to check ATM numbers still fit runway constraints. If they do the model is said to have converged for that year, if not the iterative process continues until a solution is found in which both types of capacity are not exceeded at any airport, or in practice not allowed to exceed the user input tolerances allowed to ensure model convergence is achieved.

3.59 This process means that forecasts of passenger numbers at airports under capacity constraints takes into account capacity at all airports. These forecasts are also based on passengers’ observed airport choice behaviour.

Relationship between capacity, demand and aircraft size

The relationship between aircraft size and airport capacity is complex. The historical relationship between aircraft size and passenger demand at the route level shows a well-established correlation between increasing aircraft size and rising passenger demand. When this relationship is extended into the future, adding new airport capacity accommodates increased route level demand and aircraft sizes can grow.

However, a shortage of runway or terminal capacity can also favour the use of larger aircraft, to maximise the number of passengers using scarce slots. In the model this is represented when a runway shadow cost rather than terminal shadow cost is applied. The model tests for breaches of both runway and terminal capacity with runway constraints regarded as more 'binding' than terminal where both are becoming overloaded. All shadow costs are ultimately added to the individual passenger's overall cost of travel. But a runway constraint will stimulate the use of larger aircraft and higher passenger loads because airlines can better meet demand with larger more fully loaded aircraft and because the charge levied on the use of the runway is lower on a per passenger basis for more fully loaded aircraft. Conversely a terminal shadow cost will not penalise the use of smaller aircraft, usually found on shorter haul routes.

The range of business models adopted by different airlines will play a part - the full extent of which is hard to replicate exactly in this type of model. For example, some airlines may place greater emphasis on frequency and having services conveniently timed throughout the working day and may maximise profits on certain routes with more frequent services operated by smaller aircraft.

Overall, the most prevalent effect in the model is in line with the underlying historic data of aircraft loads tending to increase as demand rises. However, the capacity response effect also occurs, and in practice the response to capacity limits varies between airlines depending on their differing business models and commercial objectives.

3.60 Shadow costs have two significant effects on the allocation of demand:

- some passengers in the model will be re-allocated to an alternative, less-congested airport but such 'less-preferred' airports may also in turn experience changes in shadow costs and affect further airports; and
- some passengers in the model will decide not to fly, reducing the total amount of passenger traffic travelling through UK airports

3.61 Higher shadow costs increase the total cost of travel, leading some passengers to decide not to travel by air at all: this process is known as 'suppression'. The modelling reflects this by adding shadow costs to the generalised cost and applying the NAPDM fare elasticities to dampen demand.

Model performance: Passengers and ATMs 2019

3.62 The 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 are undertaken for:

- 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.[40]

3.63 This model version continues to use the underlying demand data based on 2011-2016 CAA passenger interviews for the base demand matrix. In total over 1.1 million interviews over the period were utilised to build origin-destination base demand matrices by airline type and journey purpose. A light touch review of this underlying demand has been conducted using 2019 CAA survey data with minor adjustments applied where the underlying demand is showing significant shortfalls compared to 2019 data.

3.64 The model will therefore be thoroughly quality checked on its performance against observed aviation activity immediately before the disruption to the industry caused by the COVID-19 pandemic.

3.65 Further details of summarising the performance of the model’s passenger to airport allocations (including competing major overseas hubs) against statistical outturns (‘actuals’) provided by the CAA for 2019 will be provided in a future publication on aviation forecasts forthcoming in 2024.

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[40] 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.

Summary of changes in NAPAM since TR17 and Jet Zero to now

3.67 Table 3-5 shows how the model has been developed from 2017 to Jet Zero to now

	2017	Jet zero	Now
Geography: Modelled airports	32 modelled airports	29 modelled airports	Same as Jet zero
Geography: England, Wales, Scotland	455 district based zones	Same as 2017	Same as 2017
Geography: Northern Ireland	Modelled as “add-ins”	37 new zones to model the same as the rest of the model	Same as Jet zero
Model Performance: Validation year	Validated to 2016 actuals	Validated to 2019 actuals	Same as Jet zero
Logit model choice base year	Parameters estimated from 2008 data	Same as 2017	Parameters estimated from 2015 data
Logit model choice international parameters	Frequency, flight time, surface access costs	Same as 2017	Addition of fare for some markets
Logit model choice domestic parameters	Surface mode treated as an additional choice alongside all airports	Same as 2017	Surface mode vs air treated as a nested choice before choice of airport
Airline market split logit choice model	Separate logit choice model parameters	Same as 2017	No separation of logit choice model parameters based on airline
Value of Time	Higher	Same as 2017	Lower
Airline market split segments	3 airline type segments	Same as 2017	Same as 2017
International destination zones	3 zones based on short haul US and long haul (excluding US)	Same as 2017	4 zones based on NAPDM regions of SE, RoE, OECD, RoW
Model Performance Market segments	22 market segments	Same as 2017	31 market segments
Airport capacity	All airports have runway and terminal capacity	Only runway capacity required	Updated runway capacity
Airport capacity tolerances	Within 5000 ATMs	Within 1000 ATMs	Same as Jet zero
Demand matrices	Based on 2011-2016 CAA survey data	Light touch review based on 2019 CAA survey data	Same as Jet zero

Table 3-5: Summary of changes in NAPAM from 2017 forecasts and Jet Zero publications

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. [41] This model continues to take base year age distributions of ATMs by specific aircraft type at all the main UK airports and forecast the future changes to that composition, having applied assumptions about:

- the retirement age of each aircraft type
- typical replacements for each aircraft type each year.

4.2 The FMM has been integrated inside the NAPAM calculation of ATM demand and determines the forecasted fleet at a route level. Once the aircraft types on a route in a specific year have been allocated by the FMM, the number of ATMs required to meet the route demand are calculated from the number of available seats, considering additional factors such as load factor. Previously, fleet allocation was conducted downstream of the ATM airport and route allocation and therefore applied to the forecast at an aggregate national level as shown in Figure 4-1.

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[41] https://assets.publishing.service.gov.uk/media/5e8dec2786650c18c9666633/uk-aviation-forecasts-2017.pdf

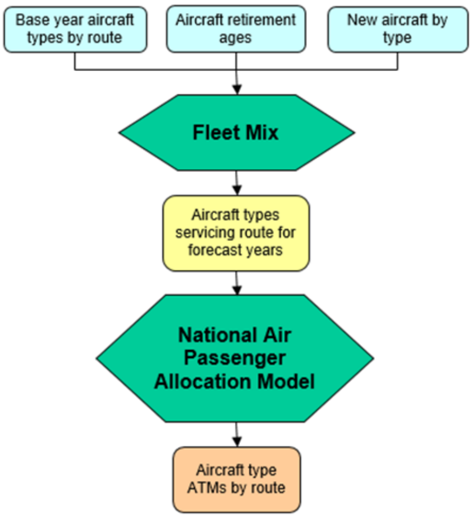

Figure 4-1: Fleet modelling methodology

4.3 The present and future fleet compositions are applied to each route and airline type using the 135 airline and route specific aircraft sizing graphs held within NAPAM's ATM model. This integration has delivered several advantages on the modelling used for the 2017 forecasts:

- increased granularity – fleets are now 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 747-400s
- greater precision on the future types of aircraft carried forward into the carbon modelling.

Model base year – Aircraft types

4.4 The incorporation of route specific fleet modelling into NAPAM allows a granular application of the forecast fleet turnover. In the base year, aircraft are applied to routes based on movements recorded by the CAA departing UK airports.

4.5 The mechanism by which aircraft are applied to routes is the 135 airline and route specific aircraft sizing graphs held within NAPAM's ATM model. These graphs describe the relationship between demand (required seats) and the number of ATMs required to service this demand on specific types of routes. To convert from route demand to aircraft movements, the sizing graphs holds details on the number of seats on aircraft servicing each route and airline type. They also instigate the point of transition to using aircraft of increased size to service greater demand.

4.6 In the FMM, up to three aircraft types will be allocated to each sizing graph, either side of any transition points. For example, a sizing graph that represents two aircraft sizes for differing demand can have up to 6 aircraft types allocated to it. A representative size of the allocated aircraft types within each size band is carried forward to the ATM calculation.

4.7 The second key input to the FMM is the age profile of aircraft operating in the UK. This determines when a specific airframe will retire from the fleet and its replacement be introduced. The age distribution of the UK fleet is produced by combining the details of all commercial aircraft movements recorded by the CAA at UK airports in 2017 with a current fleet inventory database.[42]

Model performance – Aircraft types

4.8 Having used produced assumptions on the base fleet age distribution, expected aircraft retirement ages and expected replacements from the future supply pool, the FMM was validated against CAA records of the fleet operating at UK airports in 2019.

4.9 Details summarising the performance of the modelled fleet against statistical outturns (‘actuals’) provided by the CAA for 2019 will be provided in a forthcoming publication on aviation forecasts due in 2024. This performance will be assessed in terms of the total number of ATMs by aircraft type.

4.10 This publication will also illustrate how the fleet evolves over the forecast period as the base fleet is replaced.

Aircraft fleet replacement modelling

4.11 The evolution of the composition of future UK fleets of ATMs is governed by assumptions in the supply pool. The supply pool is composed of existing and future aircraft types expected to come online and form part of the fleet of ATMs using UK airports and is also informed in the near term by current manufacturer order books.

4.12 The methodology within the FMM has the supply pool assigning a direct replacement type for each aircraft present in the base fleet. Replacement types are available for up to three generations of aircraft, all containing entry into service (EIS), phaseout and

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[42] All UK aircraft movements with registration mark data were provided by the CAA. Fleet inventory data is provided by the Cirium fleet analyzer. This provides details of aircraft registrations and associated information such as model type, manufacturer, operator/owner details, manufacture year, age, and activity status.

retirement date[43] assumptions. The FMM retires aircraft from the UK fleet as they reach a certain age, assumed to be 23 years.[44] The year an aircraft retires will determine which future generation of aircraft will be the replacement. This is depicted by the graphical representation of the baseline aircraft type supply pool in Annex G.

4.13 Generally, the generations of aircraft are:

- named types currently being manufactured (this can be the same as the retiring aircraft, in essence an aircraft is replaced by itself)
- named types expected to be in production within the next few years
- generic type (not associated with specific manufacturers or models) expected in future waves.

4.14 The supply pool assumptions have been independently peer reviewed in 2023 by York Aviation Limited (YAL). The future supply pool assumptions about replacement aircraft types have been updated in line with recommendations provided as part of this review. In several instances, the DfT supply pool assumptions deviate from the YAL recommendations for modelling purposes. These are highlighted and explained in Annex E.

4.15 The current supply pool assumptions consider impacts of the COVID-19 pandemic, particularly regarding widespread retirements of legacy wide body aircraft.

Passenger load factors

4.16 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 throughput of passengers. Potentially higher load factors mean using fewer ATMs to meet demand and consequently fewer CO_2e emissions. This latest version of the model accurately represents the recent rise in passenger load factors.

4.17 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.[45] So although the size in terms of seats has been

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[43] Phaseout date refers to the date at which no new aircraft of this type will enter the fleet. Any aircraft in the fleet at this time will remain in the fleet until its retirement. Retirement date refers to the date at which all aircraft of this type leave the fleet, irrespective of whether an aircraft has reached it retirement age or not.

[44] Determined from analysis conducted in 2019 of IBA fleet data. Previous retirement age assumptions in the 2017 forecasts where split by Scheduled, Charter and Low Cost carrier types but due to convergence between these types this distinction has been removed.

[45] 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%).

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.

4.18 The methodology behind the input of load factor growth assumptions had 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 [46]. 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.[47]

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

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

[47] 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.

5. Modelling aircraft CO_2e emissions

Introduction

5.1 Aviation CO_2e emissions are directly related to the amount and type of aviation fuel consumed. There are therefore four key drivers of aviation CO_2e 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,
- type of fuel or power utilised by aircraft: the CO_2e emissions associated with a given amount of fuel burn will fall as the penetration of alternative fuels and power sources increases.

5.2 The key inputs to the fuel burn and CO_2e 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.

5.3 NAPAM now forecasts ATMs by specific aircraft types. On each route these aircraft types flying in and out of the UK are output as ATM-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 CO_2 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.[48]

5.4 It should be noted that since the 2017 forecasts were published the metric used by the department for reporting emissions is now by default CO_2e ('CO_2 equivalent') rather than CO_2. In practice when kerosene is burned, small amounts of other greenhouse gases (included in the Kyoto Protocol) are also emitted including methane (CH_4) and nitrous oxide (N_2O). While we do not explicitly model non-CO_2, the emissions forecasts are uplifted accordingly.[49] However, the amounts are small – they equate to around 1% of the global warming potential of the CO_2 itself.[50]

Modelling aircraft fuel burn

5.5 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).[51]

5.6 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. 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.

5.7 In the CO_2 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

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[48] Evidence from a study by Ricardo Energy & Environment (for the European Commission, DG MOVE) indicates that average extra distance flown (Above Great Circle Distance) is between 4.5% and 5% for flights in Europe. https://ec.europa.eu/transport/sites/transport/files/2017-03-06-study-on-options-to-improve-atm-service-continuity-in-the-event-of-strikes.pdf). Anther study (Reynolds, 2009) indicated that an extra distance flown on North Atlantic routes was 5%, while the extra distance on typical Europe-SE Asia routes was 7%.

[49] We are engaging with academics and industry to continue to develop our understanding of this question and potential metrics to capture the non-CO_2 effects.

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

[51] 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.

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 CO_2e modelling process, Ricardo Energy & Environment provided advice on mapping aircraft types to those in the EEA guidebook. The review also 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.

5.8 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 CO_2e methodology is largely unchanged from the department’s 2017 forecasts.

5.9 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 efficiency

5.10 Seat-kilometres per mass of fuel (i.e. seat-kilometres per tonne or kg of fuel) is the department’s preferred metric for measuring aviation fuel efficiency. The value of this metric is that it is essentially unaffected by the assumed or modelling load factors.

5.11 Gains in the fuel efficiency of air travel on the metric of seat-kilometres delivered per tonne of fuel can be split into two sources:

- **Air traffic management and operational efficiencies**: better co-ordination and control of air transport movements, elimination of non-essential weight, optimisation of aircraft speeds, limits to the use of auxiliary power etc, will result in less fuel being needed for each seat-kilometre flown.
- **Aircraft efficiency**: as new, more efficient aircraft replace older aircraft, the average efficiency of the fleet will rise. Improvements in new aircraft efficiency can be driven by better engine or airframe technology. These gains could take the form of new types of aircraft entering production (e.g. Boeing 787 or Airbus A350) or incremental improvements to existing types of aircraft (e.g. new engine options in the Airbus A320 or Boeing 737 families). It is also possible for certain existing aircraft to become more efficient through retrofitting of the latest engine technology or the fitting of aerodynamic devices such as winglets and riblets.

5.12 In 2018 the department, jointly with the CCC, commissioned research[52] 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). The generic assumed future aircraft types ('NextGen') are modelled with fuel efficiencies reflecting this research.

Sustainable aviation fuels

5.13 The facility to include profiles for the annual uptake of sustainable aviation fuels (SAF) is included in the CO_2 model. The use of SAF does not in itself increase fuel efficiency (the amount of fuel burn per distance flown), but it will increase CO_2 efficiency (the amount of CO_2 emissions per distance flown). Details on specific SAF uptake profiles applied in the CO_2 model will be provided alongside published forecasts.

5.14 It should be noted that, depending on the production technology employed, the lifecycle emissions savings that SAF achieves compared to kerosene can vary significantly on a lifecycle basis,. However, the SAF Mandate has been designed to ensure that SAF achieves an average of 70% GHG savings across the UK. Therefore, the assumption in the model is that SAF delivers 70% lifecycle savings compared to Kerosene.

Fuel burn to CO_2e emissions

5.15 Once the above method has forecast the amount of fuel that is burned on flights departing each airport on each route by aircraft type, this is converted into CO_2 emissions on the basis that 1kg of kerosene emits 3.15kg of CO_2.[53] As mentioned previously, a factor of 1.01035 is then applied to convert CO_2 to CO_2e emissions. Where SAF uptake is assumed, this average carbon intensity factor is reduced.

Which emissions are being counted?

5.16 The scope of aviation CO_2e 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

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[52] Understanding the potential and costs for reducing UK aviation emissions: report to the Committee on Climate Change and the Department for Transport (publishing.service.gov.uk) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/785685/ata-potential-and-costs-reducting-emissions.pdf)

[53] Each 1kg of kerosene contains 815g of carbon and each 1kg of carbon is equivalent to 44/12 or 3.67kg of CO_2. 0.858 * (44/12) = 3.15

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

5.17 It is also important to recognise that some actions or events that reduce UK inventory aviation CO_2e emissions do not necessarily reduce global aviation CO_2e 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 CO_2e emissions modelling here is aircraft departing UK airports. The value of using the NAPAM model (see Chapter 2) 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 2 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.

5.18 The sources of emissions covered in the forecasts in this chapter are set out in Table 5-1 . The approach used is consistent with the DESNZ outturn estimates and the UNFCCC recommended approach for reporting on CO_2e emissions from international aviation. The sources of CO_2e included in the forecasts are those using A1-Jet fuel/Kerosene and exclude the light aircraft using aviation spirit/Avgas to reconcile with DESNZ bunker fuel returns of A1-Jet fuel. Thus, business jets using jetfuel are included as part of the residual (see below),[54] 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	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

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[54] 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.

Emissions source	Included in forecasts?
International flights arriving in the UK	No
Overflights passing through UK airspace	No

Table 5-1 : Included emissions sources.

Validation of emission forecasts with aviation bunker fuel data

5.19 The new baseline forecasts using the updated FMM and CO_2 models have been validated against base year CO_2e actuals for 2019. In common with established national reporting practice, CO_2e is counted for departing aircraft only.

5.20 Aviation emission forecasts are adjusted to match the Department for Energy Security and Net Zero (DESNZ) estimate of 2019 outturn (i.e. published) aviation CO_2e emissions (using the UNFCCC reporting method), as reported in the National Atmospheric Emissions Inventory (NAEI). The estimates of outturn CO_2e emissions from aviation are based on the amount of aviation fuel uplifted from bunkers at all UK airports.

5.21 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.[55] The department adjusts to aviation bunker-fuel based returns with a supplementary residual which is added to the modelled CO_2e and held constant throughout the forecast period.

5.22 A positive CO_2e residual value is to be expected and the scale of the residual is monitored to ensure it is within acceptable tolerances.

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[55] In addition to allowing for aircraft and fuel burn modelling error, the residual must also accommodate any asymmetries in inbound and outbound flight refueling caused by the practice of 'tankering'. It excludes light aircraft using Avgas.

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	-1
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
UBOECD (UK business other OECD)	*0.9*	*0*	0.1	0
UBRoW (UK business Rest of the World)	*0.9*	*0*	0.4	-0.6
ULSE (UK leisure Southern Europe)	*1.2*	*-0.7*	1	-1.1
ULRoE (UK leisure Rest of Europe)	*1.2*	*-0.7*	1	-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	-0.9
FBSE (Foreign business Southern Europe)	*1*	*-0.2*	1.1	-0.1
FBRoE (Foreign business Rest of Europe)	*1*	*-0.2*	0.7	-0.3
FBOECD (Foreign business other OECD)	*0.5*	*-0.2*	0.9	0
FBRoW (Foreign business Rest of the World)	*0.7*	*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
Overall	*1.1*	*-0.6*	1.2	-0.9
All business	*1*	*-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
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

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.

Annex B: 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	DESNZ	Year	$ / barrel (2015 prices)
Carbon prices UK ETS	DfT series	Year, UK / EEA	£/CO_2 (2015 prices)
Carbon prices CORSIA	DfT series	Year, long-haul	£/CO_2 (2015 prices)
SAF Uptake	SAF Mandate	Year	Percentage of jet fuel
SAF Prices	SAF Mandate	Year	£/tonne (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 = $\alpha + \beta x OilPrice$)	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)

Data	**Source**	**Aggregation level**	**Unit**
Average trip length	NAPAM	Domestic / global region, journey purpose	Km
CO_2e content of fuel (carbon intensity)	DfT CO_2 model		

Annex C: NAPAM International zone definitions

Zone code	**Zone Name**	**Haul**	***Former zone***	**Changed?**	**NAPDM**	**EU/ETS**
5001	US East	L	*513*	N	OECD	
5002	US West	L	*512*	N	OECD	
5003	Canada East	L	*503*	N	OECD	
5004	Canada West	L	*502*	N	OECD	
5005	Caribbean	L	*522*	Y	RoW	
5006	Mexico	L	*522*	new	OECD	
5007	Chile	L	*522*	new	OECD	
5008	South America (other)	L	*522*	Y	RoW	
5009	Australia & New Zealand	L	*526*	Y	OECD	
5010	South Pacific (other)	L	*526*	Y	RoW	
5011	Africa West	L	*519*	N	RoW	
5012	Africa East	L	*520*	Y	RoW	
5013	Africa South	L	*521*	N	RoW	
5014	China (Incl.Hong Kong)	L	*525*	Y	RoW	
5015	Japan & South Korea	L	*525*	new	OECD	
5016	Far East (other)	L	*525*	Y	RoW	
5017	Indian Sub-continent	L	*524*	Y	RoW	
5018	Asia (other)	L	*518*	Y	RoW	
5019	Middle East	L	*523*	Y	RoW	
5020	Israel	S	*523*	new	OECD	
5021	Russia & non-EU former Soviet	S	*518*	Y	RoE	
5022	Ireland	S	*511*	N	RoE	EU
5023	Channel Islands	S	*527*	N	RoE	EU
5024	France	S	*505*	Y	RoE	EU
5025	Belgium & Luxembourg	S	*501*	N	RoE	EU
5026	Netherlands	S	*510*	N	RoE	EU
5027	Germany	S	*506*	Y	RoE	EU
5028	Scandinavia (EU)	S	*516*	Y	RoE	EU
5029	Baltic States	S	*518*	new	RoE	EU
5030	Poland	S	*518*	new	RoE	EU
5031	Central Europe (EU)	S	*517*	Y	RoE	EU
5032	Bulgaria & Romania	S	*518*	new	RoE	EU

Zone code	**Zone Name**	**Haul**	***Former zone***	**Changed?**	**NAPDM**	**EU/ETS**
5033	Iberian Peninsula	S	*514*	Y	SE	EU
5034	Canary Islands	S	*504*	N	SE	EU
5035	Italy	S	*509*	Y	SE	EU
5036	Greece-other, EU eastern Med	S	*507*	Y	SE	EU
5037	Iceland (& Greenland)	S	*508*	N	RoE	(ETS)
5038	Norway	S	*516*	new	RoE	(ETS)
5039	Switzerland (& Liechtenstein)	S	*517*	new	RoE	
5040	Non-EU Balkan	S	*515*	new	RoE	
5041	Turkey	S	*515*	new	SE	
5042	African Mediterranean	S	*519/520*	new	RoW	
5043	Dublin	S	*529*	N	RoE	EU
5044	Brussels	S	*532*	N	RoE	EU
5045	Berlin	S	*506*	new	RoE	EU
5046	Dusseldorf	S	*534*	N	RoE	EU
5047	Hamburg	S	*545*	N	RoE	EU
5048	Munich	S	*537*	N	RoE	EU
5049	Copenhagen	S	*535*	N	RoE	EU
5050	Stockholm	S	*540*	N	RoE	EU
5051	Budapest	S	*517*	new	RoE	EU
5052	Vienna	S	*541*	N	RoE	EU
5053	Alicante	S	*514*	new	SE	EU
5054	Barcelona	S	*543*	N	SE	EU
5055	Madrid	S	*536*	N	SE	EU
5056	Malaga	S	*514*	new	SE	EU
5057	Lisbon	S	*546*	N	SE	EU
5058	Milan	S	*539*	new	SE	EU
5059	Rome	S	*538*	new	SE	EU
5060	Athens	S	*544*	N	SE	EU
5061	Oslo	S	*542*	N	RoE	(ETS)
5062	Geneva	S	*547*	N	RoE	(ETS)
5063	Zurich	S	*533*	N	RoE	(ETS)
5064	Paris CDG	S	*528*	N	RoE	EU
5065	Amsterdam	S	*530*	N	RoE	EU
5066	Frankfurt	S	*531*	N	RoE	EU
5067	Dubai	L	*523*	Y	RoW	
5068	UK offshore	S	*599*	N	UK	

Annex D: Airport capacity assumptions

	Runway ATMs (000s)				Terminal passengers (millions)			
Airport	**2019**	**2030**	**2040**	**2050**	**2019**	**2030**	**2040**	**2050**
Gatwick	290	346	383	386				
Heathrow	480	505	740	740				
London City	111	111	111	111	6.5	9	9	9
Luton	160	190	213	213	18	28	32	32
Stansted	264	264	264	264	35	43	43	43
Southampton	150	150	150	150	2.5	3	3	3
Southend	53	53	53	53				
Bournemouth	150	150	150	150				
Bristol	150	86	86	86	10	12	12	12
Exeter	150	150	150	150				
Newquay	75	75	75	75				
Cardiff	105	150	150	150				
Norwich	175	175	175	175				
Birmingham	205	205	205	205				
East Midlands	263	263	263	263				
Doncaster/Sheffield	0	0	0	0				
Humberside	150	150	150	150				
Leeds-Bradford	150	150	150	150	5	5	5	5
Liverpool	213	213	213	213				
Manchester	324	400	500	500				
Newcastle	213	226	226	226				
Teesside	150	150	150	150				
Aberdeen	175	225	225	225				
Edinburgh	150	225	225	225				
Glasgow	226	226	226	226				
Inverness	150	150	150	150				
Prestwick	150	150	150	150				
Belfast City	48	48	48	48				
Belfast International	260	260	260	260				

	Runway ATMs (000s)				Terminal passengers (millions)			
Airport	**2019**	**2030**	**2040**	**2050**	**2019**	**2030**	**2040**	**2050**
Paris	690	690	690	690				
Amsterdam	500	500	500	500				
Frankfurt	700	700	700	700				
Dubai	560	1051	1146	1666				

Annex E: Fleet model aircraft supply pools

The aircraft type supply pool and replacement are graphically represented in the figure below. Note that the Fleet Mix Model (FMM) supply pool only allows each aircraft type to have one direct replacement.

The figures within this Annex are split by aircraft manufacturer for clarity. This, however, does not mean that all aircraft are replaced by an aircraft from the same manufacturer.

Updates to the supply pool, implemented since the publication of the Jet Zero modelling framework[56], are in line with the recommendations provided by York Aviation Limited (YAL) as part of their peer review. Most deviations from these recommendations are small and are implemented to remove any gaps between the retirement and entry into service (EIS) dates for different generations of aircraft replacements.

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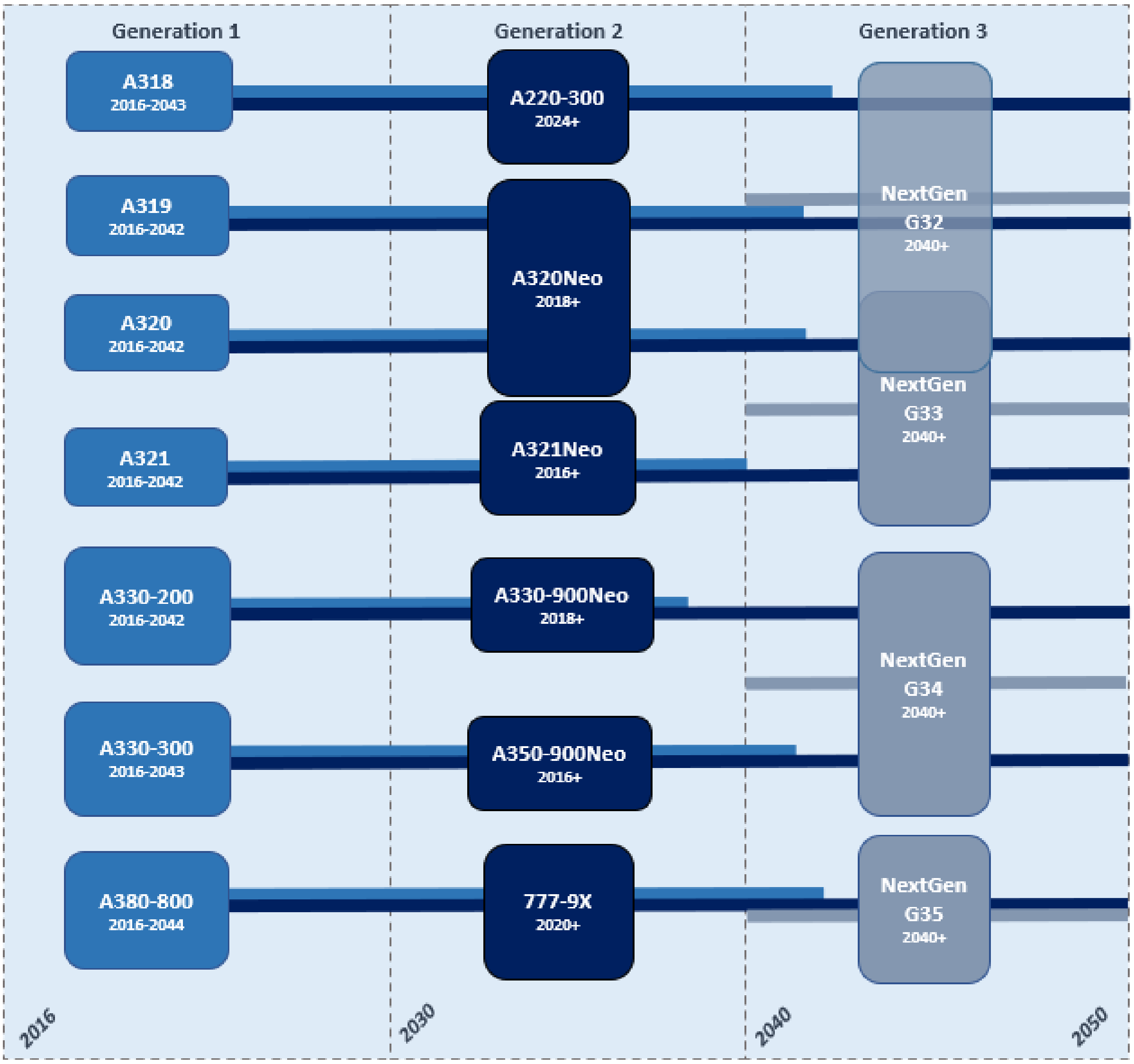
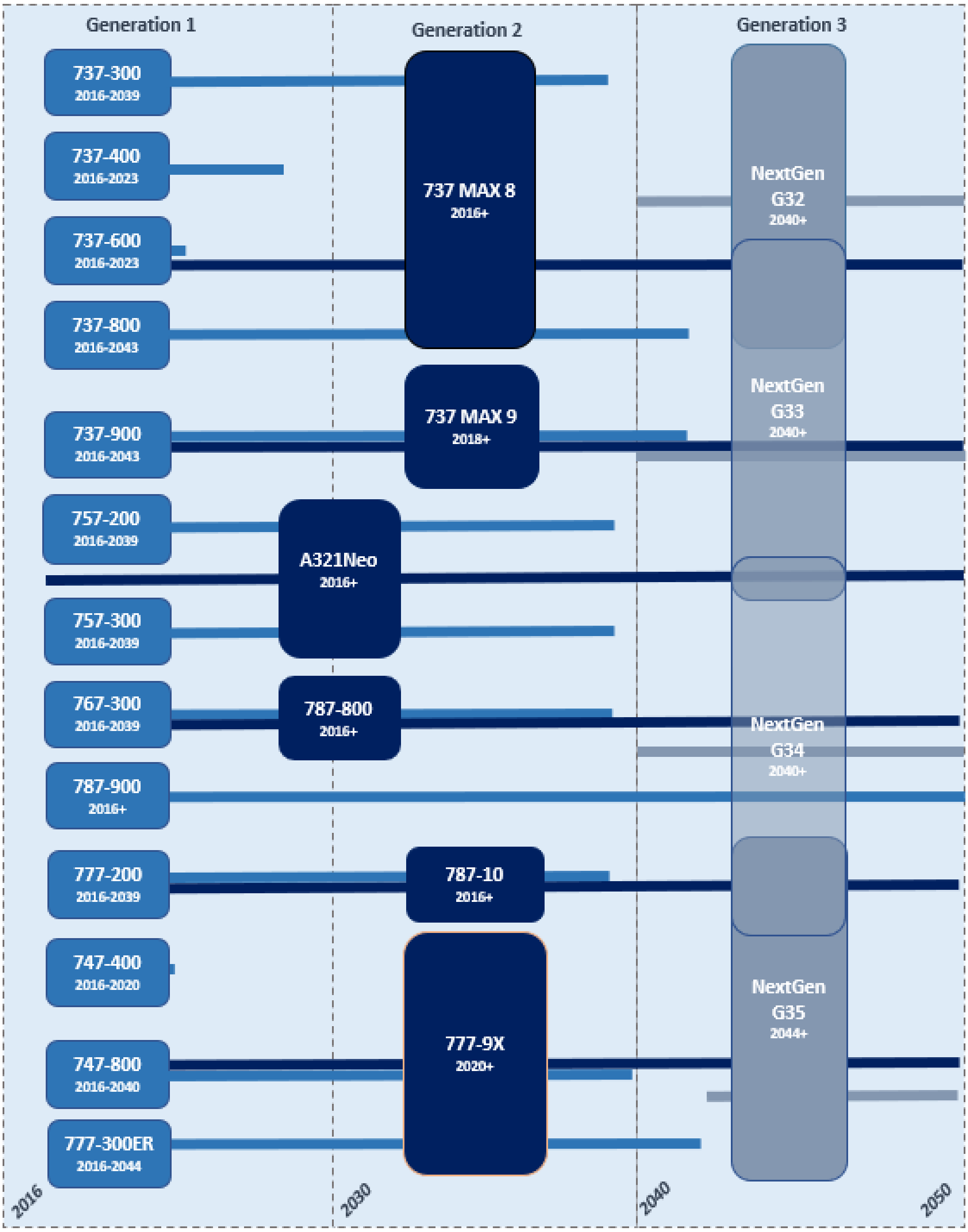
[56] Jet zero: modelling framework (publishing.service.gov.uk), Annex G: Fleet model aircraft supply pools

Airbus



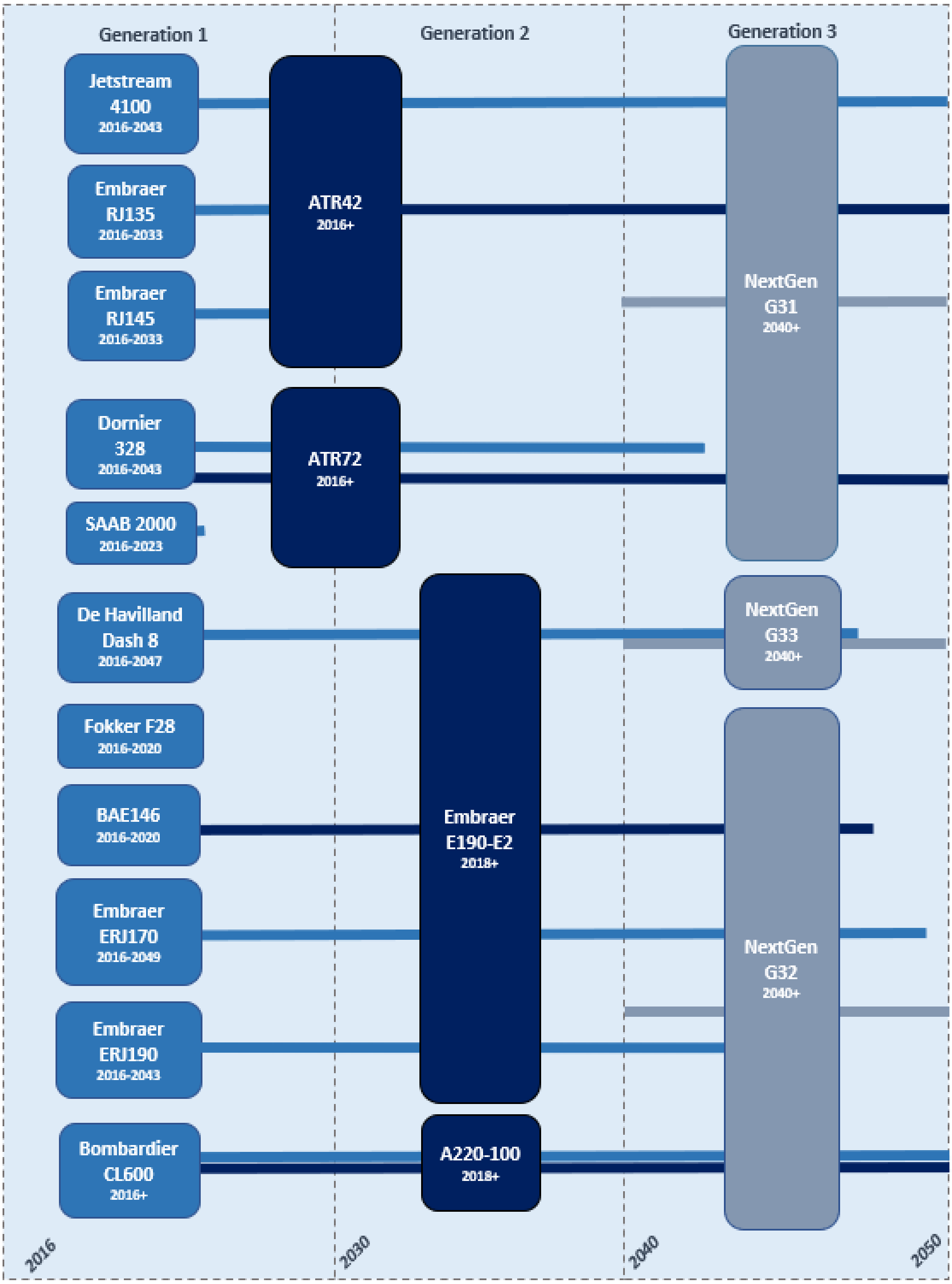
NextGen Code (*GYC*)		Introduction Date		Seat Class	
Y	introduction date	2	post 2030	1	0 - 70
C	Seat Class	3	post 2040	2	71 -150
				3	151 - 250
				4	250 - 350
				5	350 - 500

Boeing



Note: 777-9X EIS of 2020. Based on market analysis YAL recommend an EIS of 2025 for the 777-9X. YAL suggest in the interim period between the 747-400 retirement and 777-9X EIS dates that the 747-400 is replaced by either the A350-1000 or 777-300ER. The FMM currently has no facility to include a 4th generation aircraft replacement type, therefore adding an interim replacement is not possible within the constraints of the model. Ultimately the 777-9X is deemed the intended to be the replacement for the 747-400 in the long term so this deviation from YAL recommendations is proportionate in the context of a long-term forecast.

Others


Generation 1
Generation 2
Generation 3
Jetstream 4100
2016-2043
Embraer RJ135
2016-2033
Embraer RJ145
2016-2033
ATR42
2016+
NextGen G31
2040+
Dornier 328
2016-2043
ATR72
2016+
SAAB 2000
2016-2023
De Havilland Dash 8
2016-2047
NextGen G33
2040+
Fokker F28
2016-2020
BAE146
2016-2020
Embraer E190-E2
2018+
Embraer ERJ170
2016-2049
NextGen G32
2040+
Embraer ERJ190
2016-2043
Bombardier CL600
2016+
A220-100
2018+
2016
2030
2040
2050

Annex F: Glossary

Term	Description
Aircraft-kilometres, Aircraft-km	The number of kilometres travelled by an aircraft
APD	Air Passenger Duty
ATM	air transport movement (i.e. a commercial aircraft flight)
ATM demand model	Part of NAPAM which calculates the number and size (seats) of ATMs needed to serve the demand allocated to the route
Baseline	Case where no new runway is added
CAA	Civil Aviation Authority
CAEP	The Committee on Aviation Environmental Protection
Capacity constrained	Modelling case where passenger and ATM demand must fit available future capacity where no significant additional runway or terminal capacity is added
CCC	Committee on Climate Change (independent government advisory body)
CH4	Methane
Charter	As determined by the CAA, flights sold in holiday packages and not operating to schedule
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent – includes and uplift to forecast carbon dioxide to allow for other greenhouse gases methane (CH4) and nitrous oxide (N2O) emitted when jet fuel is burnt
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation (ICAO)
DESNZ	Department for Energy Security and Net Zero (UK government)
DFT	Department For Transport
Domestic passenger	Passengers who complete an end-to-end journey with the UK
EEA	European Environment Agency
ETS	Emissions Trading Scheme
EU ETS	European Union Emissions Trading System

Term	Description
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
GDP	Gross Domestic Product (national income)
GDHI	Gross Domestic Household Income
GVA	Gross Value Added – a measure of production of goods and services in an area
HMRC	Her Majesty Revenue and Customs
IATA	International Air Transport Association (airline trade body)
ICAO	International Civil Aviation Organisation
International-international	International-international transfer passengers, i.e., passengers who are transferring via a UK airport or one of the four overseas hubs in the model with their origin and destination outside the UK
IMF	International Monetary Fund (economic forecaster)
IPS	International Passenger Survey
LCC	Low-cost carrier: low-cost carriers apply a business model that relies on reducing operating costs to provide passengers with relatively cheap tickets - only includes easyJet, Ryanair, Jet 2 and scheduled Thomsonfly services in the department's model
LDC	Less Developed Country, a NAPDM long-haul forecasting region
LRTAP	Long Range Transboundary Air Pollution
Load factor	The proportion of seats on an ATM utilised by passengers
Long-haul	'Long-haul' depicts a destination (or route) to or form an overseas country that is not listed as part of the group of countries defined 'Western Europe' (or 'short-haul')
Model base year	The year from which the majority of underlying model data is taken, and the first year of model output
N_2O	Nitrous Oxide
NAAM2	National Airport Accessibility Model, generation 2, a model used to extract travel costs by road and rail from all districts to all mainland UK airport
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
NIC	Newly Industrialised Country, a forecasting region in NAPDM
NTEM	National Trip End Model (DfT model)
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
PIANO	An aircraft engine fuel-burn modelling tool
Runway capacity	The annual number of aircraft movements that are able to use an airport's runways and supporting airside infrastructure

Term	Description
Scheduled (Sch)	In the department modelling suite, scheduled carriers refer to only those carriers operating to a schedule, have been defined as such by the CAA and do not fall in the DfT definition of low-cost carriers
Seat-kilometres, seat-km	The number of kilometres travelled by an aircraft multiplied by the number of seats
Shadow cost (also referred as congestion premium)	The extra cost of flying required to reduce passenger demand from above an airport's runway or terminal capacity, to a level that is back within
Short-haul	'Short-haul' has been defined as 'Western Europe' which comprises the following groups of countries: Andorra; Austria; Belgium; Bosnia and Herzegovina; Cape Verde; Channel Isles; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Faroe Island; Finland; France; Germany; Gibraltar; Greece; Greenland; Hungary; Iceland; Ireland; Italy; Latvia; Lithuania; Luxembourg; Macedonia; Malta; Republic of Moldova; Monaco; Montenegro; Netherlands; Norway; Poland; Portugal; San Marino; Serbia; Slovakia; Slovenia; Spain; Sweden; Switzerland; and Turkey. This is consistent with the definition of 'Western Europe' used in the department's aviation modelling suite.
Suppression	The process whereby passengers respond to a shadow cost by deciding not to fly rather than using a 'less preferred' airport
Surface access	Land-based forms of transport used to access airport
Terminal passenger	A person joining or leaving an aircraft at a reporting airport, as part of an ATM
Terminal capacity	The annual number of terminal passengers that are able to use an airport's terminals including its supporting landside infrastructure
UNECE	United Nation Economic commission for Europe
UNFCCC	United National Farmwork Convention on Climate Change
VFR	Visiting Friends and Relatives
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