Department for Transport

Revised Fuel Efficiency Assumptions for Future Aircraft Types in DfT's Aviation Modelling Suite

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1. Executive Summary

1.1 The Department for Transport (DfT) relies on its aviation modelling suite to forecast air passengers, aircraft movements and CO2e emissions at UK airports[1]. This report details a collaborative project between the Department for Transport (DfT) and the Aerospace Technology Institute (ATI) to provide evidence for DfT to update fuel efficiency assumptions within its aviation modelling suite.

1.2 The Aerospace Technology Institute (ATI) were chosen for this collaboration as they are a leading, independent organisation with cross-sector expertise, that develop the national technology strategy for the UK's civil aerospace sector[2].

1.3 The project focused on future aircraft types, assumptions around their fuel efficiency and Entry Into Service (EIS) dates. Future aircraft types are aircraft yet to be formally announced by Original Equipment Manufacturers (OEMs). The technologies for these aircraft are currently in development. These aircraft are likely to be ultra-efficient conventionally powered[3] aircraft (hereafter labelled 'ultra-efficient') or zero-emission aircraft (ZEA)[4].

1.4 Inherent uncertainty in adoption of future technologies was explored through scenario analysis. These scenarios are:

- Low scenario - Assumes no ZEA and slow development of ultra-efficient aircraft.

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[1] https://assets.publishing.service.gov.uk/media/668546fa541aeb9e928f43eb/dft-aviation-modelling-framework.pdf

[2] The ATI provides funding for research projects that align with the strategy through a joint government-industry programme and promotes innovation to ensure the UK remains competitive in the global aerospace market and continues to lead the sector's decarbonisation. Working with programme partners at Department for Business and Trade and InnovateUK, they assess projects requesting funding in the ATI strategic, SME and Non-CO2 programmes, which combined provide approximately £195million of funding per year to the UK aerospace sector. The technical insight and modelling capability at the ATI gives them a comprehensive understanding of the likely technical developments for the aerospace sector. The ATI team consists of technologists whom all have experience of working in the aerospace sector or highly related disciplines. The technologists work alongside a strategy team who identify opportunities for the sector to grow and expand with the ultimate aim of improving UK aircraft share.

[3] Aircraft which can be powered conventionally (via kerosene) or via Sustainable Aviation Fuel (SAF)

[4] Aircraft which is zero-emission at the tailpipe, for example through electric or hydrogen power

- Mid scenario - Reflects current policy ambition and aligns with the 'Current Trends' scenario in the 2022 Jet Zero Strategy. Assumes development of both ultra-efficient aircraft and ZEA, but ZEA will not be prominent in the UK fleet until after 2050.

- High scenario - Equivalent to the 'High Ambition' scenario in the Jet Zero Strategy. Assumes development will focus solely on ZEA for smaller aircraft types, while narrowbodies and larger aircraft will first adopt ultra-efficient technology before transitioning to zero-emission technology.

1.5 This new research has taken a fresh approach to considering the technologies that are likely to be adopted on next generation aircraft, focusing on reviewing the dates that new technologies and aircraft become available (EIS dates) and understanding the efficiency improvement once introduced[5]. This means DfT's aviation modelling suite is now up to date with the latest industry understanding on future aircraft types and their implications, enabling robust analysis of policy areas such as decarbonisation and noise into the future.

1.6 Aircraft technology is a rapidly developing area, and DfT will continue to keep these assumptions under close review.

[5] The previous research considered a range of improvements to the technology efficiencies across time (worst, best and nominal). It also included scenarios which varied the likelihood of these technologies being adopted over time (pessimistic, likely and optimistic). The new approach focusses on reviewing the dates new technologies are available and their efficiencies once introduced.

2. Introduction and Motivation

2.1 As above, outputs of DfT's Aviation model are used by analysts to assess the impact of policies aimed at decarbonising the aviation sector. Forecasts of aviation emissions are also provided to the Department for Energy Security and Net Zero (DESNZ) to support their statutory reporting requirements under the Climate Change Act. These inputs will also support the appraisal of other policy areas, such as aviation noise.

2.2 Outputs of the model are also used for internal and cross-Government policy development; outputs are occasionally published - such as in the SAF Revenue Certainty Mechanism analysis, May 2025.

2.3 The Department for Transport (DfT) follows a policy of continuous model development to ensure that outputs across all its models, including the Aviation Model, use the latest data and analytical techniques. The Aviation Model undergoes regular development cycles to maintain its fitness for purpose. DfT's current assumptions for fuel efficiency for future aircraft types are based on research conducted in 2018 by Air Transportation Analytics Ltd and Ellondee Ltd on behalf of DfT and the Climate Change Committee (CCC) in 2018[6].

2.4 This research is increasingly outdated due to significant advances in the UK's decarbonisation agenda, rapid technological progress in aircraft and engines, and evolving industry expectations.

2.5 DfT has therefore undertaken two pieces of work- the research set out in this report and a review of the modelling assumptions regarding future improvements in airline operations and airspace management, which the DfT commissioned from the Aviation Impact Accelerator (AIA)[7], a multi-disciplinary team comprising of both the Whittle Laboratory and the Cambridge Institute for Sustainable Leadership at the University of Cambridge .

2.6 The purpose of this report is to present the revised fuel efficiency assumptions following DfT's engagement with the ATI. These assumptions, alongside those from

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[6] https://assets.publishing.service.gov.uk/media/5c88ed82ed915d50b2053ea7/ata-potential-and-costs-reducting-emissions.pdf

[7] https://aiazero.org/the-team/

the separate project with the AIA, will supersede those from the 2018 research. The findings of the AIA project are also published alongside this report.

3. Overview of Available Model Inputs & Scenarios

3.1 This section explains the aspects of DfT's Aviation Modelling suite relevant to this review of future aircraft type fuel efficiency.

DfT's Aviation Model

3.2 DfT's Aviation Model is a suite of models – this modular structure enables DfT to forecast UK passengers, Aircraft Traffic Movements (ATMs) and CO2 whilst considering capacity constraints. The demand and allocation elements of the model provide an estimate of passengers and ATMs for groupings of routes from each UK airport. The downstream CO2 model forecasts emissions. See the modelling framework document[8] for further details.

3.3 DfT's Aviation Model forecasts passenger demand to destination zones by UK airport. The model then uses assumptions on the relationship between demand, aircraft size and frequency of service to determine the number of ATMs to serve a route.

3.4 The composition of the UK fleet is governed by supply pool assumptions. 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 informed in the near term by current manufacturer order books. The model assumes that once an aircraft retires, the aircraft is replaced by a future generation aircraft of a similar capacity, known as an aircraft type. For further information on aircraft fleet replacement modelling, see page 47 of the Aviation Modelling Framework.

3.5 The Aviation Model includes a 'feedback loop' which enables the model to account for the impact on demand associated with improvements in aircraft and engine efficiency, reducing fuel consumption, and therefore fares. This is done by feeding through fuel efficiency assumptions from a first iteration run through a second iteration run.

[8] https://assets.publishing.service.gov.uk/media/668546fa541aeb9e928f43eb/dft-aviation-modelling-framework.pdf

3.6 The inputs within the model which can be used to reflect efficiency gains for future aircraft types are summarised below.

Entry Into Service

3.7 All aircraft types have an Entry Into Service (EIS) date, which determine the year an aircraft is available and certified for commercial use. When an aircraft retires, it is replaced by a next-generation aircraft of the same type.

Retirement and Phaseout Dates

3.8 The Aviation Model also uses assumptions about phaseout and retirement dates and ages:

- Phaseout date – The year in which the model will no longer replace an aircraft of the same aircraft type.
- Retirement date – The year in which all aircraft of that type will leave the fleet, regardless of age. This was primarily used to reflect when a lot of aircraft left the fleet at the same time (e.g. B747s during the COVID-19 pandemic).
- Retirement age – The age at which an aircraft will be replaced, likely by a next-generation version of that aircraft. DfT assumes 23 years for every aircraft type – note this is the age an aircraft leaves the UK fleet.

Fuel Efficiency

3.9 The model makes assumptions on fuel efficiency for all aircraft types in the model, measured as quantity of fuel consumed (in kg) per unit of distance (in kms) travelled. The fuel efficiency is assumed to vary depending on the distance travelled for a given aircraft. This relationship between fuel efficiency and distance travelled is estimated using a series of quintic functions. These functions take the form:

3.10 $$Fuel\ Burn\ \left(\frac{kg}{km}\right) = (B_0 + B_1 * x_1 + B_2 * x_2 + B_3 * x_3 + B_4 * x_4 + B_5 * x_5) * x$$

3.11 These quintic forms vary by each aircraft type. In general, they follow the pattern as in Figure 1, whereby fuel consumption decreases relatively quickly on shorter flights, this is because aircraft burn a larger proportion of fuel during takeoff. At mid-range distances, the fuel efficiency of the aircraft continues to improve, albeit at a slower rate, this is because aircraft operate more efficiently at the higher altitudes reached during the cruise phase of flight. Towards the upper end of an aircraft's range, fuel efficiency may decrease slightly. This is because the aircraft must carry additional fuel to complete longer flights, and that fuel itself adds weight - requiring even more fuel to transport it, thereby compounding the fuel burn.

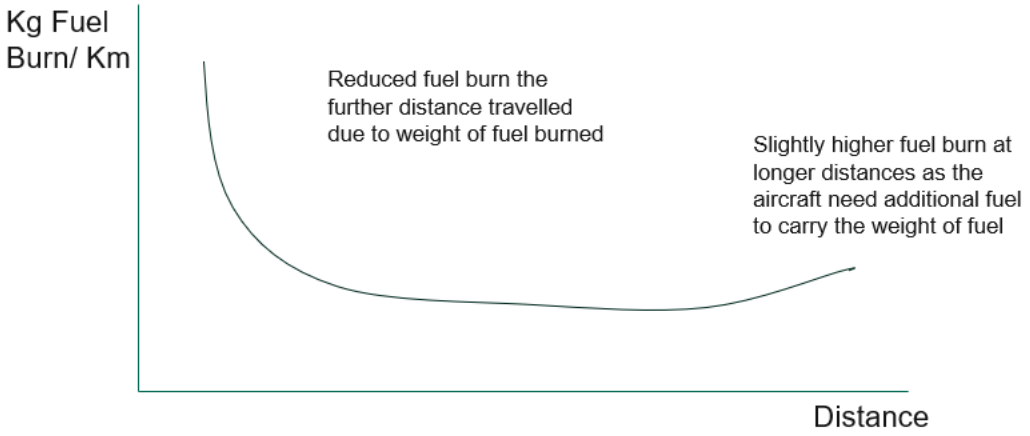


Figure 1: Illustrative fuel burn quintic function

3.12 The research outlined in this report has updated these quintic functions for future aircraft types for both ultra-efficient aircraft and zero-emission aircraft.

Costs

3.13 DfT sought to enhance its understanding of how advancements in engine and aircraft technologies affect both fixed and variable costs, enabling DfT to assess the demand impact of new technologies. There are two methods by which the DfT can estimate the demand impact of these technologies. Both methods are designed to be complementary.

3.14 The first is through the feedback loop – The feedback loop takes account of the impact of fuel efficiency on costs and is expected to be the main way variable costs are modelled. The feedback loop requires the model to undertake a first iteration model run with updated fuel efficiency assumptions. Information on seat-kms from this run is then fed back through the model in a second iteration run. Through this loop, DfT can assess the impact on fares from fuel efficiency improvements and load factors, which the model uses to assess the demand impact.

3.15 The second of these is through directly changing the fares used in the demand model. The fares in the model comprise four components: Air Passenger Duty (APD), fuel cost, carbon costs, and other costs. This can be used to account for changes in the prices of both fuel and non-fuel costs.

3.16 Engagement with the ATI quickly revealed that it would not be possible to model the fixed costs of new aircraft in the time proposed for this update. Furthermore, the cost implications of new technologies are commercially sensitive and so any estimates would likely be based on judgments rather than facts. Instead, an assumption was made that a new aircraft would not be introduced until the technology benefit had reached a point at which an operator sees a sufficient reduction in cash operating cost of the aircraft on a typical mission. The EIS data varies to account for speed of technology availability and/or policy impacts. The demand impact of improved fuel efficiency has, however, been able to be accounted for through the feedback loop.

Scenarios

3.17 DfT developed three scenarios, which were designed to map the development of technology and roll out, without being overly optimistic:

- Scenario 1 (Low) – The most pessimistic rollout and development of new technologies. This scenario assumes there are no zero-emission technologies, and the development of ultra-efficient technologies see setbacks leading to delayed EIS dates.

- Scenario 2 (Mid) – this scenario is akin to the Jet Zero Strategy 'Current Trends' scenario – assuming a continuation of current trends in the aviation sector. OEMs develop ultra-efficient and zero-emission aircraft; however, the development and EIS of zero-emission aircraft mean there is limited scope for them to capture larger proportions of the market by 2050.

- Scenario 3 (High) – this scenario is in line with the Jet Zero 'High Ambition' scenario, which assumes there is greater governmental and private sector ambition to decarbonise the sector. In this scenario, ZEA are presumed to make up a greater proportion of the fleet by 2050 than the Mid scenario, but this is still expected to be modest.

3.18 DfT has updated assumptions for fuel efficiency and EIS across all future aircraft types within the model (both zero-emission and ultra-efficient) in each of the three scenarios above.

4. Approach to Revising DfT's Fuel Efficiency Assumptions

4.1 Through their set up and work programme, the ATI is regularly engage with OEMs, Tier 1's, SMEs and academia in the UK, allowing them to assess where the UK aerospace sector sits relative to worldwide technology offerings.

4.2 The ATI use this collaboration to develop whole aircraft models which identify the performance of future aircraft concepts. These future technologies include: ultra-efficient aircraft technologies such as ultra-high bypass ratio engines, composite wings and lighter systems, and zero-carbon aircraft technologies such as hydrogen fuel cells, hydrogen gas turbines, and cryogenic fuel systems.

4.3 This performance assessment includes the generation of payload range diagrams. The whole aircraft models solve for the four forces of balanced flight (Lift, Weight, Thrust and Drag) throughout an entire mission profile, based on a time step approach, with data from the previous time step feeding into the next. These models are therefore able to provide fuel burn data for an entire mission (including take-off and landing phases that are specific to an overall mission length). The models contain a breakdown of how the engines perform against speed, altitude and ambient air temperature, as well as making predictions on the drag of an aircraft configuration. The mass of the aircraft is broken down to individual sub-systems (wings, fuselage, powerplant, landing gear, etc). This allows the impact of technologies targeting specific fuel consumption (SFC), aerodynamics and mass improvements to be assessed at the platform level. This becomes increasingly important as trades between different attributes are considered. For example, installing engines that have an improved specific fuel consumption is good for overall fuel burn, but often comes at the cost of a larger nacelle, which creates more drag and more mass (as bypass ratio increases). Therefore, the trade between SFC, mass, and drag for this new technology is important to understand, as it may not provide an overall fuel burn (gate to gate) benefit. The purpose of concept aircraft is to explore technologies and/or configuration changes and aim to balance them to optimise overall aircraft fuel burn. For example, high-aspect ratio wings are investigated in most of the future aircraft concepts. New manufacturing techniques allow different materials to be used, which then allow an increase in wing aspect ratio, which reduces induced drag, thereby improving fuel burn[9]. Each aircraft concept is iterated until the solution converges.

4.4 Working with ATI has provided DfT with access to up-to-date market knowledge as well as concept aircraft developed on engineering-focused models. This evidence enables robust assumptions regarding fuel efficiency and EIS dates. This approach means that the fuel efficiency assumptions within DfT's aviation modelling suite are now based on robust assumptions regarding future concept aircraft.

Use of DfT Aviation Model Inputs

4.5 Via ATI collaboration, it emerged that the input assumptions to be revised were fuel efficiency (through quintic functions) and EIS dates.

4.6 Other input assumptions are available within the model but were not updated during this research project for the following reasons:

- Retirement ages – DfT currently assumes a 23-year retirement age across all aircraft; this was reviewed in 2023 by York Aviation. The ATI review did not recommend moving away from these assumptions.
- Retirement date – This is only used in specific circumstances in the model and therefore was not prioritised for review.
- Phaseout date – these were reviewed in 2023 by York Aviation.
- Fare adjustments for the costs of aircraft assets – It was established that it was not possible to reflect the cost of aircraft assets in ticket prices. This is because such commercial information is not publicly available, and whilst cost information for individual aircraft do exist, aircraft lessors and airlines often receive notable discounts on these prices. As such, the only costs considered were the impact on fuel and carbon costs, as earlier explained.

4.7 DfT has separate assumptions for aircraft auxiliary power units (APU) emissions – a self-contained generator predominantly used to provide power to the aircraft whilst the main engines are inactive. These APU fuel burn assumptions are informed by the analysis of power units used on the ground at London Airports. APU fuel burn was outside the scope of the ATI's models and was therefore not updated. These are a minor part of UK aviation emissions, frequently 1% of emissions in most model runs, so the impact of not updating this assumption is negligible. Nevertheless, this has been noted by DfT as an area for future model development.

[9] If readers would like further information on the ATI's models, they may register for access via the ATI Toolkit: https://www.ati.org.uk/toolkit. Any follow up queries may be directed to the Toolkit team at toolkit@ati.org.uk.

Concept Aircraft

4.8 For these future aircraft types, DfT aligned with the ATI aircraft types where possible. Further details of the ATI aircraft types can be found here- Reference Models - ATI Toolkit.

4.9 DfT's Aviation Model requires assumptions on aircraft types and their associated seat capacity. For existing aircraft types, CAA statistics on aircraft seating densities are used. For the future aircraft types, the ATI assumes a 105kg per passenger mass. Seat counts are assumed to be the same in the future aircraft types, and so the appropriate payload matching that seat count is then used to determine mission fuel burn.

4.10 The ATI's concept aircraft met the majority of concept aircraft types required by DfT. However, there were two aircraft at the extreme ends of the aircraft capacity for which there was no concept ultra-efficient aircraft or Zero-Emission aircraft in the ATI model library. These aircraft required a bespoke approach; they are:

- Commuter Aircraft (<35 pax) – A very small number of movements of this type exist in the aviation model. Similar existing aircraft are the Dornier 228 or Saab 340.

- XL Widebody (<420 pax) – the largest aircraft in the fleet, these ATMs are few in number, but given the long-distance routes they serve, this aircraft type is significant for emissions. Equivalent existing aircraft are the Boeing 777 series.

4.11 The concept aircraft types can be summarised in the table below. The counterfactual existing aircraft are examples of the aircraft these concept aircraft will replace. The efficiency gains presented later in this document are expressed relative to these aircraft.

Aircraft Type	Capacity	Counterfactual Existing Aircraft[10]	Approach
Commuter	<35 Pax	Dornier 328	Bespoke
Regional Turboprop	<75 Pax	ATR 72 200/500/600	Adapt ATI Model Outputs
Regional Jet	<120 Pax	Airbus A220 – 100	
Narrowbody	<180 Pax	A320NEO	
Widebody	<279 Pax	Boeing 787-9	
XL Widebody	<420 Pax	777X	Bespoke

Table 1: Concept Aircraft

[10] Note these counterfactuals represent the type of aircraft the concept aircraft will replace, this list is not exhaustive and there are many aircraft types in the model the concept aircraft may replace.

4.12 Note that there is not expected to be any replacement for an A380-sized aircraft.

4.13 Discussion on the feasibility of different fuel types to power these aircraft is contained in the 'EIS Dates for Future Aircraft Types' chapter of this document.

Approach to Adapting ATI Outputs

4.14 As part of this collaboration, the ATI used its models to develop concept aircraft for the above concept aircraft types. The capabilities of these aircraft are represented through payload-range diagrams, a standard tool in the aerospace industry to represent the limitations of an aircraft. The general principle is that an aircraft can fly up to a certain range while carrying its full payload. However, as flight range increases, the aircraft must carry more fuel to reach the destination. Since fuel adds weight, and aircraft have a maximum take-off weight limit, this often requires sacrificing payload—such as passengers or cargo—to accommodate the additional fuel needed for longer flights. Note the payload in these diagrams separately account for the weight of the aircraft and crew – this means a 0kg payload means 0kg worth of passengers and cargo.

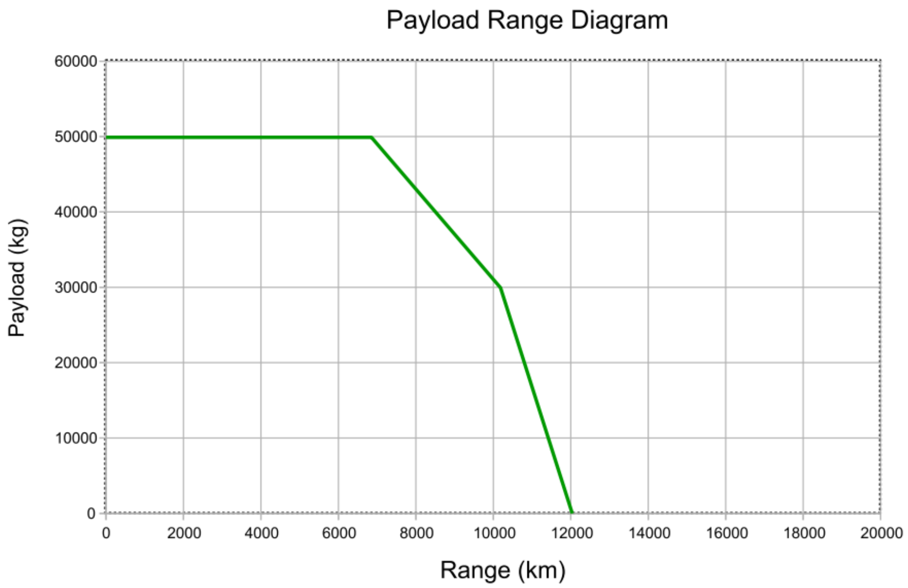


Figure 2: Illustrative payload/ range diagram

4.15 These payload range diagrams were used for each aircraft type to establish a fuel efficiency measured through Kg/Km (as required by DfT's Aviation model quintic functions) by assuming a given payload, and the range that can be met with that payload.

4.16 Given that the payload excludes the weight of the aircraft, crew and fuel, DfT analysts needed to make assumptions regarding the weight of all passengers and their luggage.

4.17 Belly hold cargo weight, outside of passenger baggage, was not considered because the DfT do not model the amount of freight carried on passenger flights.

4.18 It has been assumed that each aircraft will have a 90% load factor. The basis for this assumption is:

- DfT's load factor cap for the scheduled market is 90%, with load factors breaching 90% by a few percentage points later in DfT forecasts in the LCC market.

- Load factors change between model runs due to changes to demand and the subsequent allocation of aircraft types to routes. It would not be appropriate to change the loading and fuel efficiency assumptions for each model run in response to this, nor does the Aviation Model have the functionality to reflect changes in loading to DfT's CO2 model.

- After some diagnostic testing, aircraft efficiency was proven not to be sensitive to aircraft loading – see the Appendix for more detail.

4.19 DfT assumed that each passenger and their luggage would weigh 100kg. This is in line with industry assumptions: EASA estimate[11]. Passengers weigh on average 76.3kg; their on-board luggage 7.7kg; their hold luggage 16kg.

4.20 Bespoke approaches for the commuter and XL widebody aircraft are explained in the chapter of this document which discusses DfT's final assumptions for aircraft efficiency.

4.21 Whilst the payload range diagrams differ for a ZEA or ultra-efficient aircraft, the methodological approach outlined in this chapter to estimate aircraft efficiency are the same.

4.22 Following discussions with the ATI, it was decided not to vary aircraft efficiency by scenario. This is because OEMs are likely to invest in an aircraft's development so that it meets a certain cash operating cost improvement, which has a certain fuel burn improvement embedded within it. Of course, large fuel price fluctuations could change the required fuel burn improvement to give a set cash operating cost improvement, but as fuel price is largely governed by global political or environmental events (and are therefore less predictable), it is not something that has been assessed here. Instead, the scenarios will vary EIS dates and fuel type burned by scenario - reflecting the uncertainty in technology development and production timelines for both ultra-efficient and zero-emissions aircraft.

4.23 This document will first explain how DfT have varied EIS dates, then discuss the fuel efficiency by aircraft type and fuel.

[11] https://www.easa.europa.eu/en/newsroom-and-events/news/easa-review-standard-passenger-weights-2022-shows-no-significant-change

5. EIS Dates for Future Aircraft Types

5.1 EIS dates are a key determinant of future fleet efficiency as they determine when new technology can enter the UK fleet.

5.2 To develop EIS dates, the ATI's and DfT's understanding of the market, the development timelines of OEMs, and the focus of OEMs to likely target certain segments of the market were all considered. The following principles were followed when developing EIS dates:

- There is assumed to be no development of zero-emission aircraft in the Low scenario due to lack of technological development.
- If a scenario indicates a zero-emission aircraft is available for an aircraft type, an ultra-efficient aircraft will not be available at a later date.
- OEMs typically require a minimum of 20 years to recoup the investment from a given aircraft type.
- OEMs are likely to target more profitable segments of the market first, such as the narrowbody segment, before others.

Commuter

5.3 There are few movements of this type within DfT's model, with this aircraft primarily servicing low demand routes between regional airports. This low demand combined with other factors (e.g. airlines' preferences for fewer aircraft types in a fleet) means the market is small. Due to the small market size, both in the UK and globally, the larger OEMs do not typically invest significantly in developing this class of aircraft. There has not been a new aircraft of this type released since the 2000s.

5.4 Deutsche Aircraft are targeting the ultra-efficient D328eco for an EIS of 2027[12]. This date was used as the EIS across all scenarios, given that the aircraft is in the latter stages of development.

5.5 Given the likely emphasis on zero-emission for this aircraft type, there is assumed to be no future ultra-efficient aircraft of this type beyond 2027.

5.6 There is assumed to be no zero-emission commuter aircraft in the Low scenario due to technological barriers. Zero-emission commuter aircraft are developed in all the other scenarios. The high scenario assumes 2035 (whilst the ZeroAvia project is delayed, it's assumed a propulsor can be on a retrofitted aircraft by this date); the Mid scenario assumes 2045 as development of the technology is expected to take some time in the absence of significant changes to policy or industry ambition.

Aircraft Type	Fuel	Low	Mid	High
Commuter	Ultra-efficient	2027	2027	2027
	Zero-Emission	None	2045	2035

Table 2: EIS dates for concept commuter aircraft by scenario

Regional Turboprop

5.7 Regional Turboprops operate largely domestic and international routes between the UK and ROI in DfT's model. There are no confirmed dates for the introduction of replacement aircraft for this type, but development by OEMs is currently taking place.

5.8 In the more optimistic scenarios, it's been assumed that development of zero-emission technologies for this aircraft type will mean there will be no ultra-efficient aircraft. Therefore, there is no ultra-efficient aircraft development in the Maximum Tech Potential and High scenario. EIS of zero-emission aircraft was assumed to be 2040 in the High scenario to align with the Airbus ZEROe program. Despite the announcements in early 2025 that this program has faced delays due to slower than expected development of the required technology, 2040 was still used because this scenario is designed to reflect high ambition to decarbonise, furthermore smaller commuter and regional turboprop aircraft are likely to be the focus of technology development for ZEA aircraft.

5.9 The Mid scenario assumed an ultra-efficient aircraft in 2037 to align with the ATR ultra effect EVO programmed which is targeting the 'mid-2030s'[13]. The EIS for a zero-emission aircraft is 2057 as a 20-year development timeline is assumed from the previous ultra-efficient aircraft.

[12] https://www.deutscheaircraft.com/news/deutsche-aircraft-revises-entry-into-service-timeline-for-the-d328eco-regional-turboprop

[13] https://www.atr-aircraft.com/innovation/atr-evo-concept/

5.10 The Low scenario assumed an EIS of 2040 for the ultra-efficient aircraft based on a 3-year delay from the Mid scenario based on observed historical EIS delays. There is assumed to be no ZEA.

Aircraft Type	Fuel	Low	Mid	High
Regional Turboprop	Ultra-efficient	2040	2037	None
	Zero-Emission	None	2057	2040

Table 3: EIS dates for concept Regional Turboprops by scenario

Regional Jet

5.11 Regional Jets operate short to medium-sized routes in DfT's model, where demand is not quite strong enough to meet the market requirements of a narrowbody. There are no set dates for the introduction of replacement aircraft for this type, but development by OEMs is currently taking place.

5.12 The High scenario assumes there will be no ultra-efficient aircraft of this type, as OEMs focus efforts on developing zero-emission regional jets. 2040 was chosen in the High scenario as a 5-year development period is assumed to develop this zero-emission technology from the Regional Turboprop, this is also a ~20-year development timeframe since the EIS of the A220, which aligns with industry insights for the development timeframes.

5.13 In the Mid scenario 2037 was chosen as the EIS for an ultra-efficient aircraft as it represents ~20 years since the development of the A220, whilst there may be potential to introduce this aircraft sooner, it is presumed OEMs would focus their developments on more profitable parts of the market, such as the narrowbody. The zero-emission aircraft is estimated to enter the fleet in 2057 as a 20-year investment period is assumed from the ultra-efficient aircraft.

5.14 The Low scenario assumes no zero-emission aircraft and a 3-year development delay for the ultra-efficient aircraft relative to the Mid scenario, which would enter in 2040.

Aircraft Type	Fuel	Low	Mid	High
Regional Jet	Ultra-Efficient	2040	2037	None
	Zero-Emission	None	2057	2040

Table 4: EIS for concept Regional Jets by scenario

Narrowbody

5.15 Narrowbody aircraft operate short and medium haul routes from the UK. The latest generations of narrowbodies, such as the A321NEO XLR operate a number of long-haul routes from the UK, such as London to New York, but these are relatively few in number. Narrowbodies make up a significant proportion of the fleet in the UK, they are the workhorses for the LCC fleet and operate the majority of full service carriers European routes.

5.16 There are no set dates for the introduction of replacement aircraft for this type, but development by OEMs is currently taking place.

5.17 The High scenario assumed an ultra-efficient EIS of 2035 – Boeing and Airbus have targeted a new narrowbody for the 'mid 2030s' and 2035 is the most realistic interpretation of that. The zero-emission aircraft in the High scenario is due to enter the fleet in 2051, which is based on a 16-year delay for the mid-size aircraft in Airbus's ZEROe programme.

5.18 The Mid scenario uses a later interpretation of the Airbus and Boeing's '2030' narrowbody target, using of 2037, accounting for some potential development delays. A zero-emission aircraft is assumed to enter in 2061 as OEMs use the knowledge developed from the Regional Turboprop and Regional Jet aircraft to develop the larger narrowbody zero-emission aircraft, 2061 was chosen as it assumes a 24-year development timeframe.

5.19 The Low scenario assumes a 3-year delay to the Mid scenario assumption, a longer delay of 3 years was chosen (relative to the previous delays of 2 years), due to the complexities of developing a larger narrowbody aircraft compared to a regional. There are assumed to be no zero-emission narrowbody aircraft.

Aircraft Type	Fuel	Low	Mid	High
Narrowbody	Ultra-Efficient	2040	2037	2035
	Zero-Emission	None	2061	2051

Table 5: EIS for concept Narrowbodies by scenario

Widebody

5.20 Widebody aircraft mainly operate long haul routes from the UK, with a small proportion of routes used to service short to medium haul routes to other hub airports such as Madrid and Istanbul. There are no set dates for the introduction of replacement aircraft for this type, but it is likely the development in smaller aircraft classes will lead to development for widebody aircraft.

5.21 Due to the complexities of zero-emission technologies for larger aircraft, only the High scenario assumes there will be scope for the development of both an ultra-efficient and zero-emission widebody aircraft. 2037 is the presumed EIS date for an ultra-efficient aircraft, which assumes a 25-year development timeframe since the Boeing 787 entered service in 2012. 2064 is the EIS for a zero-emission equivalent, an assumption informed by a 13-year development timeline from the narrowbody zero-emission aircraft.

5.22 The Mid scenario assumes a 3-year delay to the High scenario estimate for ultra-efficient aircraft. There are not assumed to be any zero-emission widebodies due to technological hurdles in developing widebody ZEA.

5.23 The Low scenario assumes a 3-year delay to the Mid scenario estimate. There are not assumed to be any ZEA in this scenario. A 3-year delay allows the scenarios to reflect a reasonable range of timeframes following a review of delays to previous aircraft programs.

Aircraft Type	Fuel	Low	Mid	High
Widebody	Ultra-Efficient	2043	2040	2037
	Zero-Emission	None	None	2064

Table 6: EIS for concept Widebodies by scenario

XL Widebody

5.24 Large widebodies are primarily used to service high demand long haul routes, in particular from Heathrow, the UK's hub airport, and Manchester to the Middle East. OEMs have recently introduced efficient aircraft of this type; it is anticipated there will be significant development timelines for the next ultra efficient XL widebody. This concept aircraft is similar in size to the 777X, and smaller than the A380. There is assumed to be no replacement A380 sized aircraft.

5.25 Across all scenarios, it is assumed there will be no zero-emission XL widebody as the technology may not be possible to make such large aircraft commercially viable as any XL widebody is not expected to have the range capabilities to meet the needs of the market.

5.26 The concept ultra-efficient aircraft is a replacement to the 777X, the assumptions are informed by assumed delays from the EIS of the 777X. The High scenario assumes a 25-year interval; a 27-year interval in the Mid scenario; and a 31-year interval in the Low scenario. The EIS of the XL widebody is presumed to be 2052, 2054 and 2058 respectively.

Aircraft Type	Fuel	Low	Mid	High
XL Widebody	Ultra-Efficient	2058	2054	2052
	Zero-Emission	None	None	None

Table 7: EIS for concept XL Widebodies by scenario

Final EIS Dates

5.27 This document has explained the rationale for DfT's revised EIS dates in modelling – and the technology available (Ultra-Efficient or zero-emission) available for each concept aircraft, the table below summarises the EIS for these concept future aircraft types.

Aircraft Type	Fuel	Low	Mid	High
Commuter	Ultra-Efficient	2027	2027	2027
	Zero-Emission	None	2045	2035
Regional Turboprop	Ultra-Efficient	2040	2037	None
	Zero-Emission	None	2057	2040
Regional Jet	Ultra-Efficient	2040	2037	None
	Zero-Emission	None	2057	2040
Narrowbody	Ultra-Efficient	2040	2037	2035
	Zero-Emission	None	2061	2051
Widebody	Ultra-Efficient	2043	2040	2037
	Zero-Emission	None	None	2064
XL Widebody	Ultra-Efficient	2058	2054	2052
	Zero-Emission	None	None	None

Table 8: EIS for all concept aircraft by scenario

6. Revised Fuel Efficiency Assumptions

6.1 Section 4 explained the methodological approach for developing fuel efficiency assumptions for use in DfT's aviation model. This chapter explains those revised fuel efficiency assumptions for each concept aircraft, for each fuel type (ultra-efficient or Zero-Emission). While quintic functions are the input into the model, this paper will present plotted functions to aid understanding of the changes in fuel efficiency for each aircraft type over distance travelled.

6.2 This chapter compares fuel burn assumptions with fuel burn estimates of appropriate counterfactual ultra-efficient aircraft. Note this will not be possible for zero-emission aircraft for all aircraft types as there are none currently commercially available on the market. Fuel burn figures for current aircraft are taken from EMEP/EEA air pollutant emissions guidebook from 2019[14].

Commuter

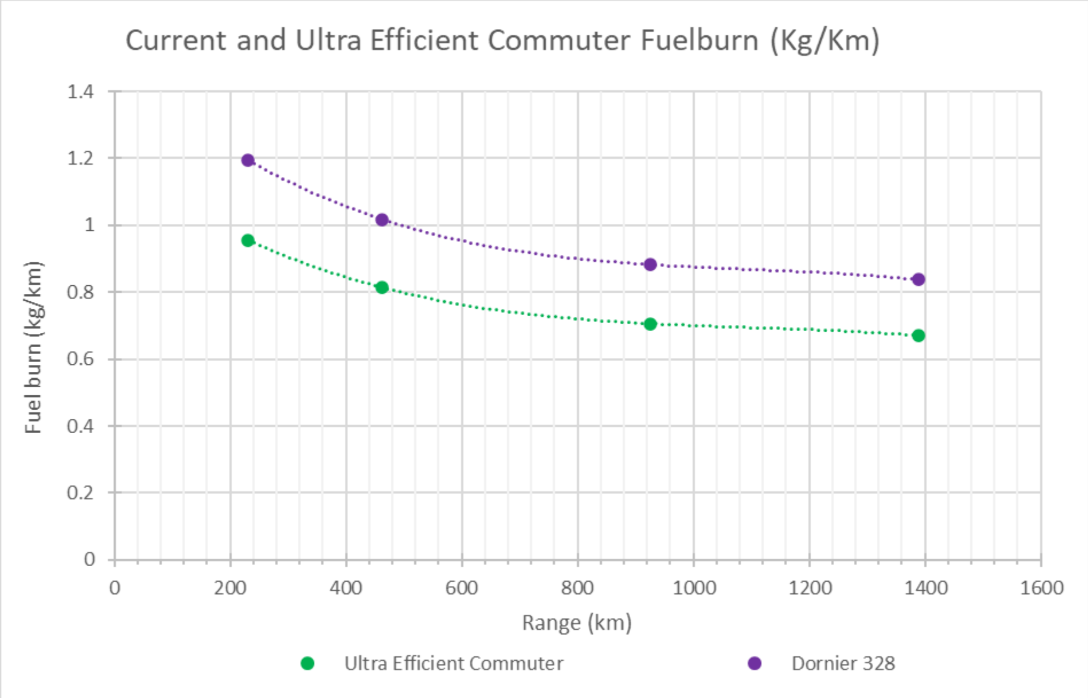
6.3 As explained above, the commuter concept aircraft was not included in the ATI's models, DfT therefore needed to take a bespoke approach for this aircraft type. There are typically very few movements of this type in the model, with commuter aircraft operating 0.5% of seat-kms in a typical model run.

Ultra-Efficient

6.4 For ultra-efficient powered aircraft, DfT has taken a proportionate approach for this aircraft type, given the small proportion of demand it serves. Deutsche Aircraft are developing the D328eco, targeting a 20% efficiency gain against the Dornier 328, DfT analysts therefore applied a 20% efficiency gain to the Dornier 328 across the entire aircraft range. This is proportionate as the D328eco is in the latter stages of development, so there is less uncertainty on the efficiency gain, and the emission impact of this assumption is likely to be minimal due to the small segment of demand the aircraft serves.

[14] https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1/@@download/file

6.5 Figure 3 illustrates the commuter fuel efficiency by range, as explained previously, the fuel efficiency per km increases over longer ranges as the take and landing contribution becomes a smaller proportion of the overall mission fuel burn.



6.6

Figure 3: Ultra-Efficient Commuter Fuel Efficiency

Zero-Emission

6.7 The ATI's models did not estimate the fuel burn for a zero-emission commuter aircraft. Due to the small proportion of seat-kms this aircraft type services, and the lack of alternative approaches available, DfT analysts have, with ATI approval, adopted the efficiency gains from ultra-efficient Regional Jet to ZEF Regional Jet. An efficiency gain of 58% was applied to the ultra-efficient Commuter with a 10% penalty applied due as there are limits to scaling down Hydrogen fuel engines.

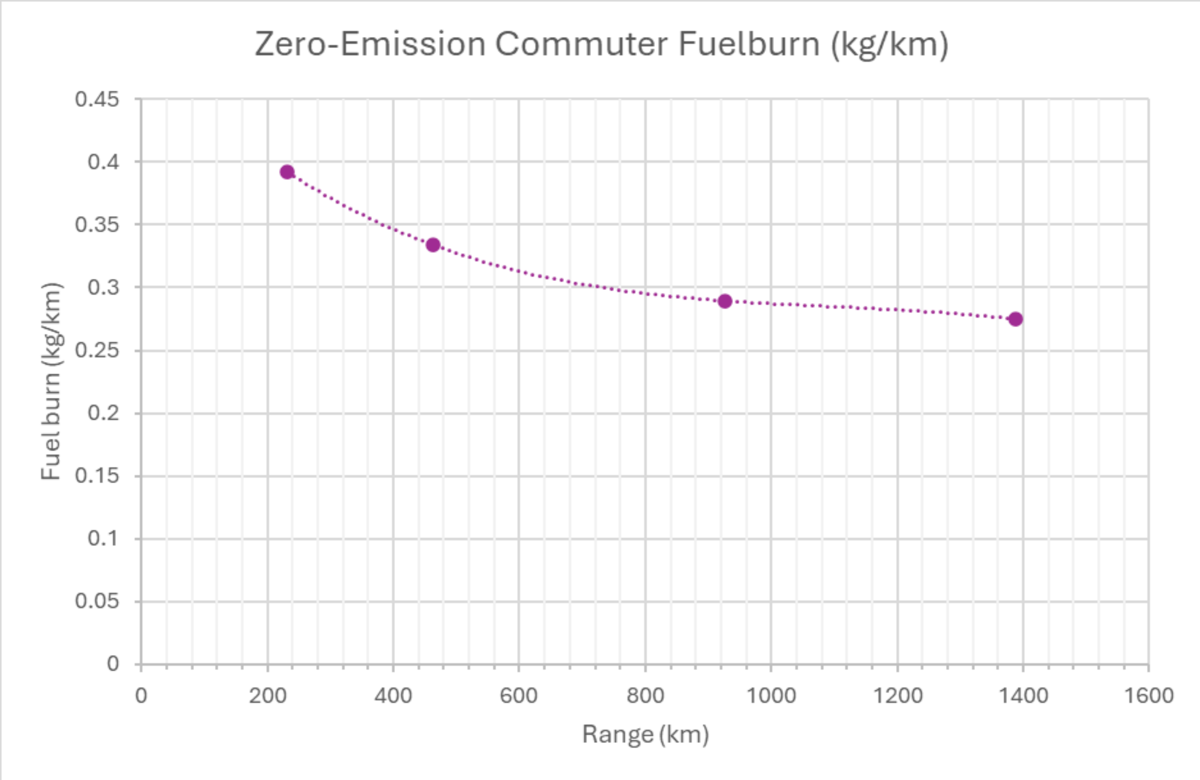


Figure 4: Commuter Zero-Emission Fuel Efficiency

Regional Turboprop

6.8 The Regional Turboprop aircraft has ultra-efficient and Zero-emission variants, with either both or just one of the fuel powered aircraft existing in the scenarios. The ATI's modelling suite was applicable for both aircraft types in the model.

Ultra-Efficient

6.9 Market analysis by the ATI suggested that a larger range would be needed for this aircraft type, therefore it's assumed that manufacturers are likely to focus on range over efficiency. The fuel burn profile for this aircraft shows that the aircraft becomes more fuel efficient as the aircraft breaches flights of 500+km. Figure 5 illustrates the concept ultra-efficient Regional Turboprop fuel efficiency against that of the ATR72 200/500/600, its counterfactual aircraft, see the efficiency remains very similar, but the range has improved.

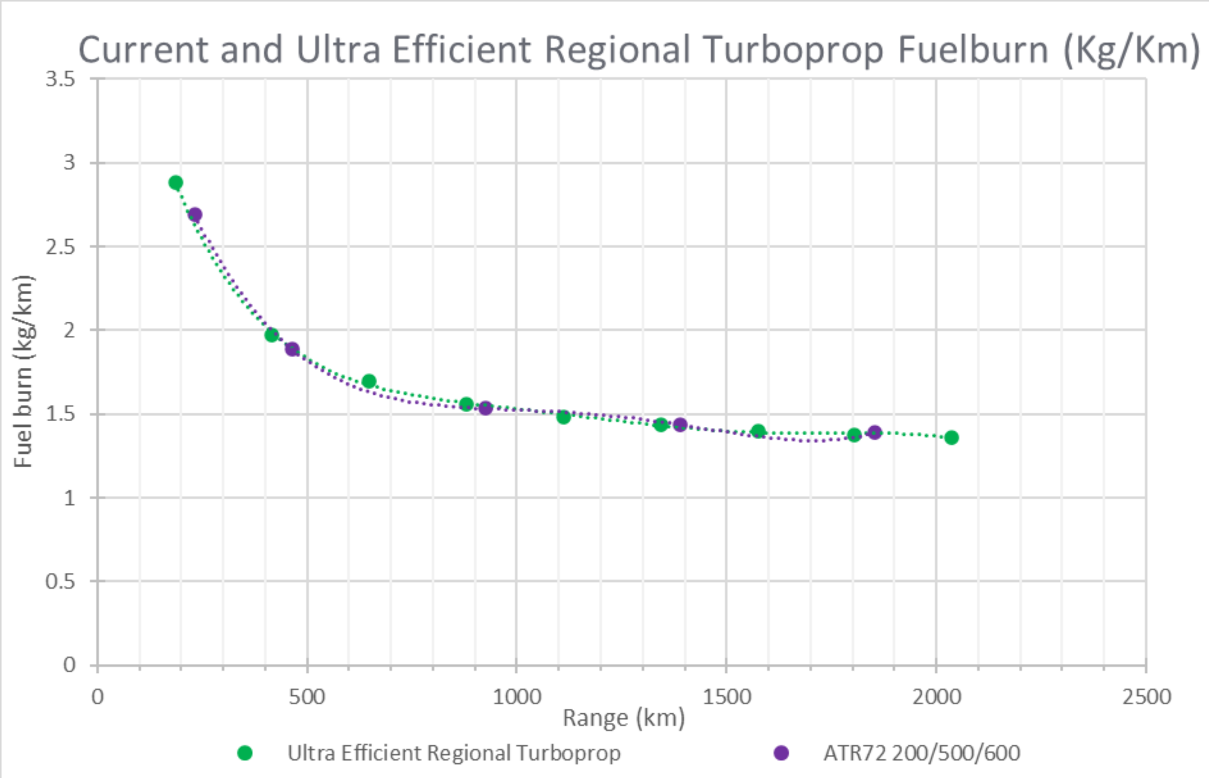


Figure 5 Ultra-Efficient Regional Turboprop Fuel Efficiency

Zero-Emission

6.10 The zero-emission Regional Turboprop follows a similar fuel burn profile as the ultra-efficient equivalent. Whilst still notable, the effect of improving efficiency at lower ranges is less pronounced. Given H2 is more energy dense than kerosene by mass, the weight of fuel required for a given distance is less than that of the ultra-efficient equivalent.

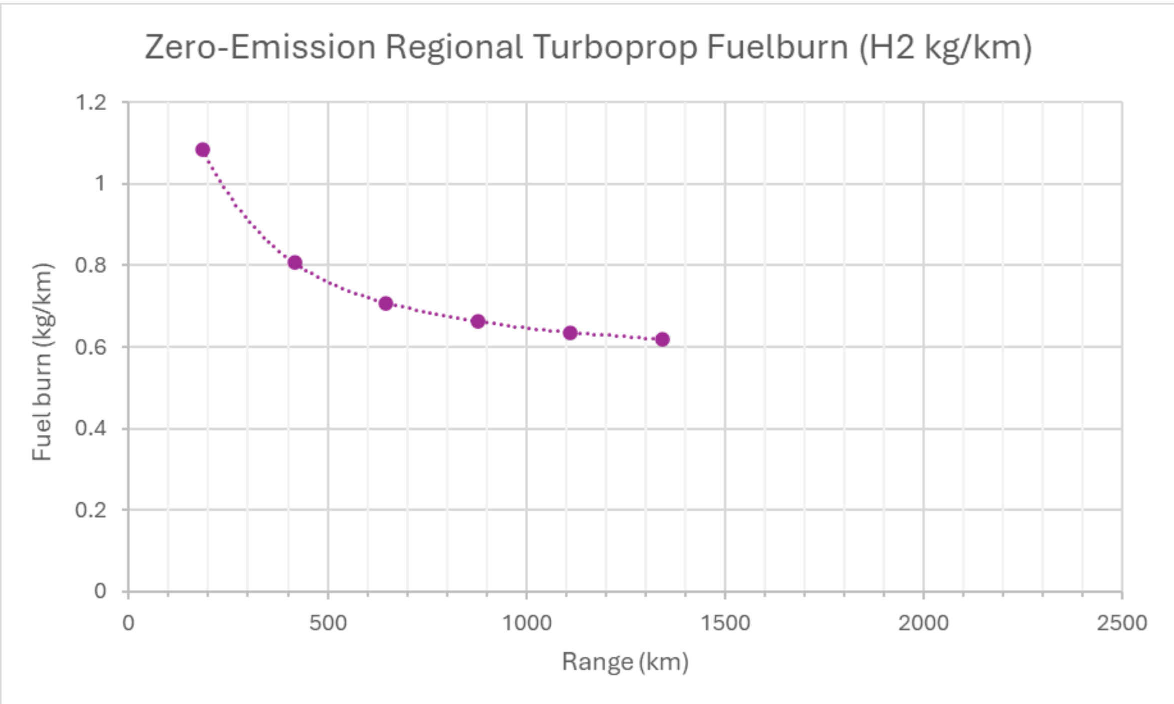


Figure 6: Regional Turboprop Zero-Emission Fuel Efficiency

Regional Jet

6.11 The Regional Jet aircraft has ultra-efficient and Zero-emission variants, with either both or just one of the fuel powered aircraft existing in the scenarios. The ATI's modelling suite was applicable for both aircraft types in the model.

Ultra-Efficient

6.12 The counterfactual aircraft for future regional jet is the A220-100, the analysis indicates there will be fuel efficiency gains of 30%-40% for this aircraft type depending on the distance travelled. Whilst fuel efficiency does decrease significantly at low ranges (<1000km), it should be noted that the majority of routes this aircraft serves are greater than 1000km, so the fuel efficiency for this aircraft type is likely to remain relatively constant across route applications within the model.

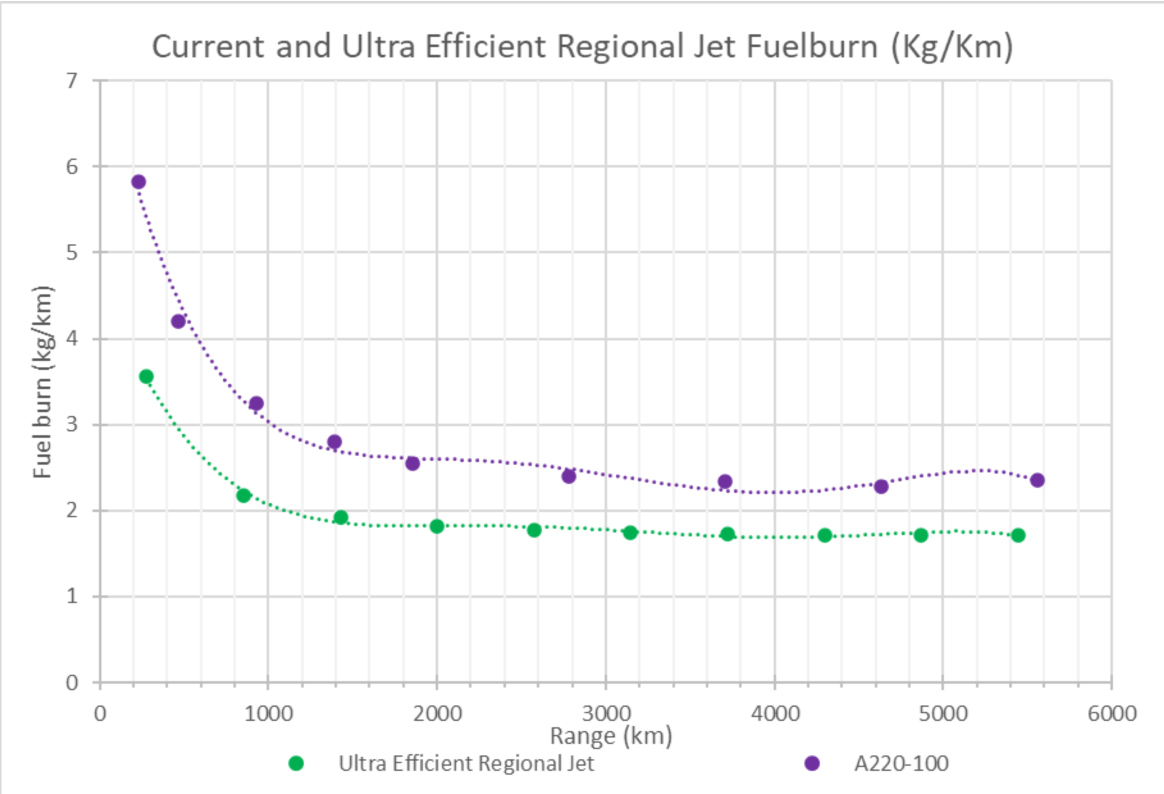


Figure 7: Ultra Efficient Regional Jet Fuel Efficiency

Zero-Emission

6.13 The zero-emission Regional Jet follows a similar fuel burn profile as the ultra-efficient equivalent. As with the Regional Turboprop, the impact of reduced weight on fuel burn at shorter flight distances is less pronounced but increases in the mid to longer ranges.

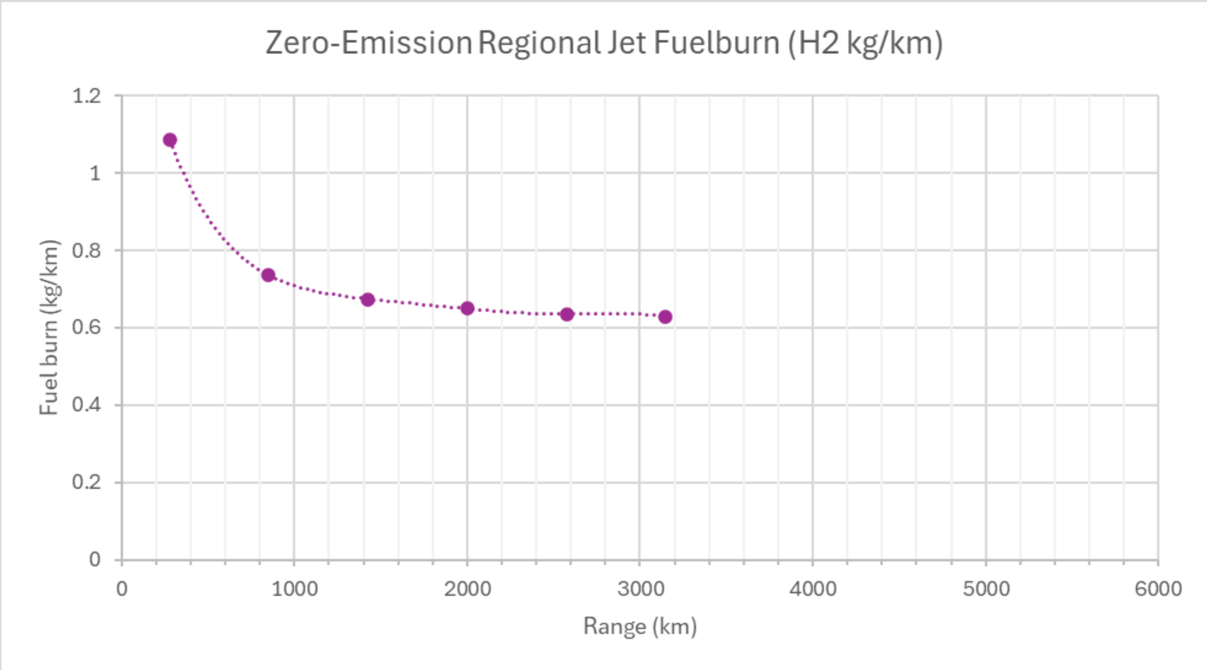


Figure 8: Regional Jet Zero-Emission Fuel Efficiency

Narrowbody

6.14 Engagement with the ATI concluded both ultra-efficient and Zero-Emission Narrowbody aircraft were possible in the scenarios, with the Zero-Emission variant being more likely in the optimistic scenarios. The ATI's modelling suite was applicable for both aircraft types in the model.

Ultra-Efficient

6.15 The counterfactual aircraft for the future narrowbody is the A320NEO. DfT's analysis indicates that the next-generation narrowbody will be 20–30% more efficient than its predecessor, depending on the distance travelled. As with the Regional Jet, fuel efficiency improves over longer distances, particularly beyond 1000 km. However, around 50% of the routes served by this aircraft type are below 1000 km in DfT's model, meaning efficiency gains will vary significantly across the route network

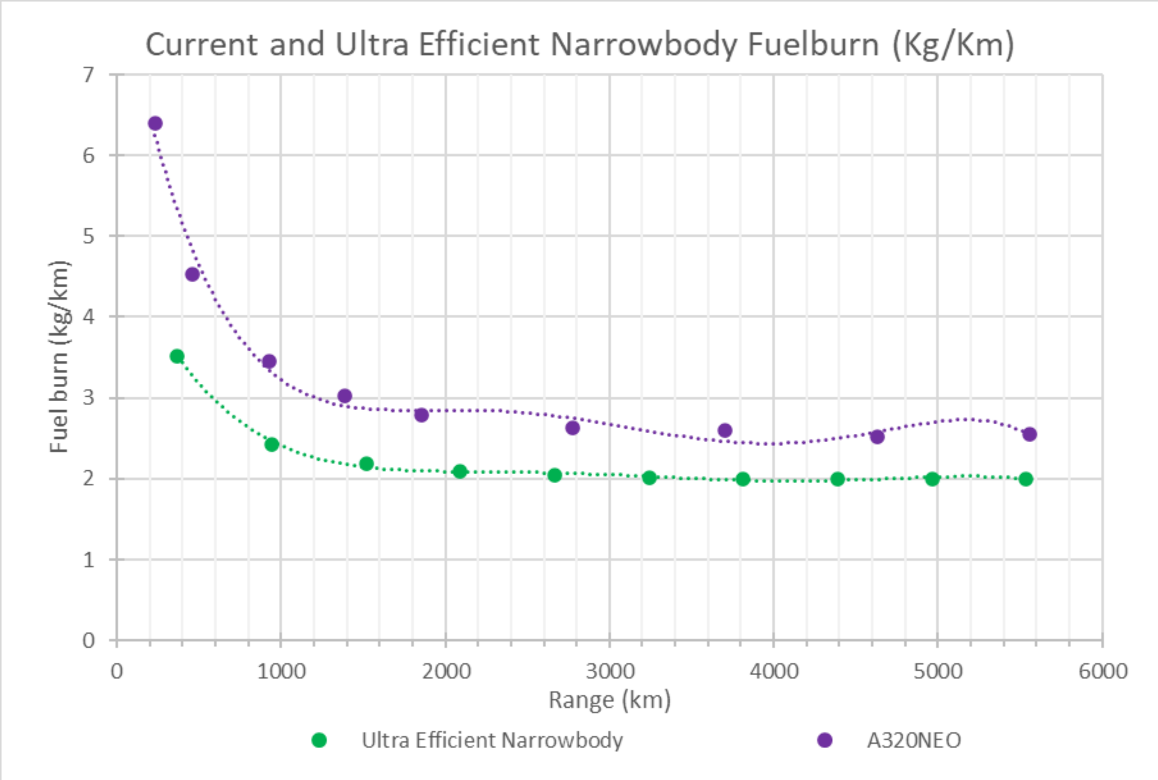


Figure 9: Ultra-Efficient Narrowbody Fuel Efficiency

Zero-Emission

6.16 The zero-emission Narrowbody follows a similar fuel burn profile as the ultra-efficient equivalent, albeit at lower absolute values due to the energy density of H2. The narrowbody is less efficient than the regional jet. At low ranges, this difference is small, but as range increase, the more energy inefficient the narrowbody is.

Figure 10: Zero-Emission Narrowbody Fuel Efficiency

Widebody

6.17 Engagement with the ATI concluded that both ultra-efficient and Zero-Emission Widebody aircraft were possible in the scenarios, with the Zero-Emission variant being more likely in the optimistic scenarios. The ATI’s modelling suite was applicable for both aircraft types in the model.

Ultra-Efficient

6.18 The counterfactual aircraft for the future Widebody is the A350-900, the analysis indicates the future widebody will likely be 15% - 25% more efficient than this predecessor. Fuel efficiency gains for new generations of aircraft are expected to be lower for larger aircraft, this is because larger aircraft, such as Boeing 787-9 are already clean-sheet designs from the 2000s, whereas existing, smaller narrowbody aircraft such as the A320 and Boeing 737 are being modified from a lower technology standard. As with previous aircraft types, fuel efficiency decreases substantially at shorter distances, until plateauing at 2000+kms. Most routes this aircraft is likely to serve will be greater than 2000kms, so the fuel efficiency is likely to be similar across the modelled routes this aircraft will serve. There is a slight decrease in fuel efficiency over longer distances, this is because the aircraft needs to carry additional fuel to carry the weight of the fuel required to service these longer flights.

6.19 Current aircraft fuel burn data is obtained from the European Environment Agency master emissions calculator[15]. The range for A350-900s range is capped at 10186km within this source data so the Boeing 737-900 Dreamliner, Boeings equivalent widebody aircraft, has been included to show the efficiency gains of the Ultra Efficient Widebody at longer ranges. DfT's aviation modelling suite utilises a linear extension on these capped aircraft to obtain the fuel burn profiles beyond the source data provided.

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

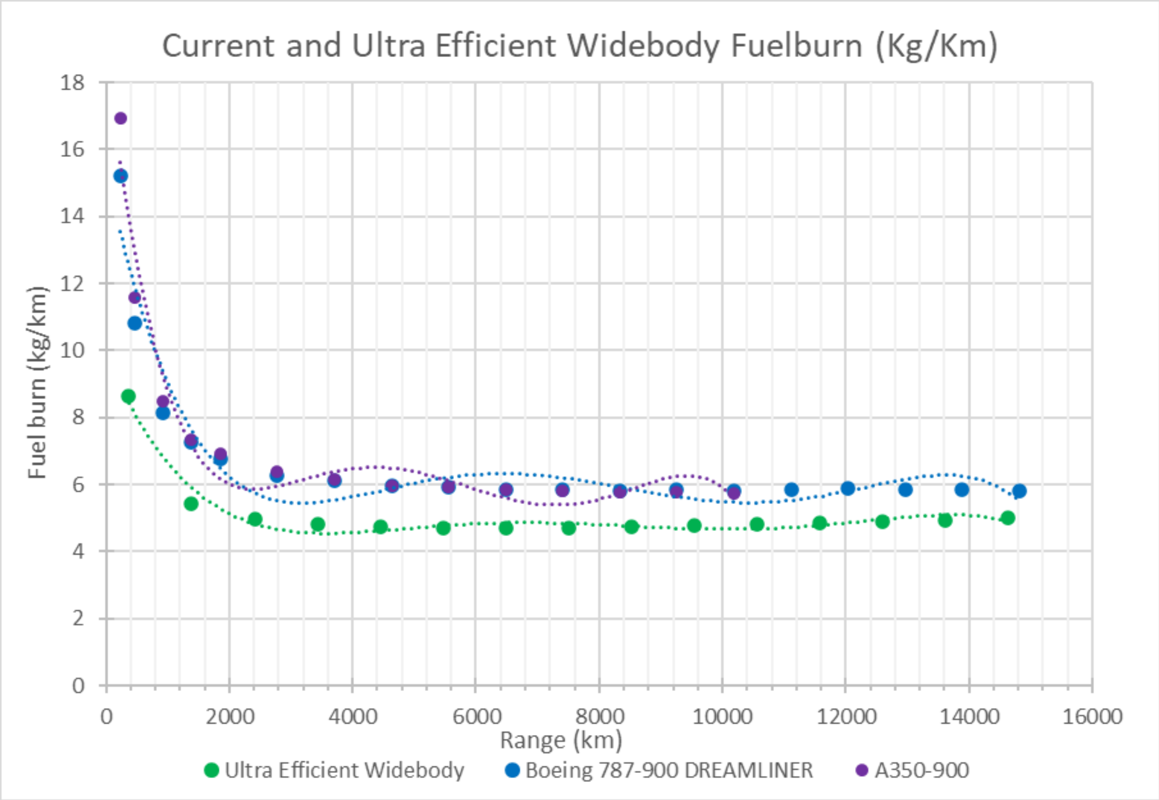


Figure 11: Ultra Efficient Widebody Fuel Efficiency

Zero-Emission

6.20 The zero-emission Widebody follows a similar fuel burn profile as the ultra-efficient equivalent at shorter-to-mid ranges of the aircraft distance.

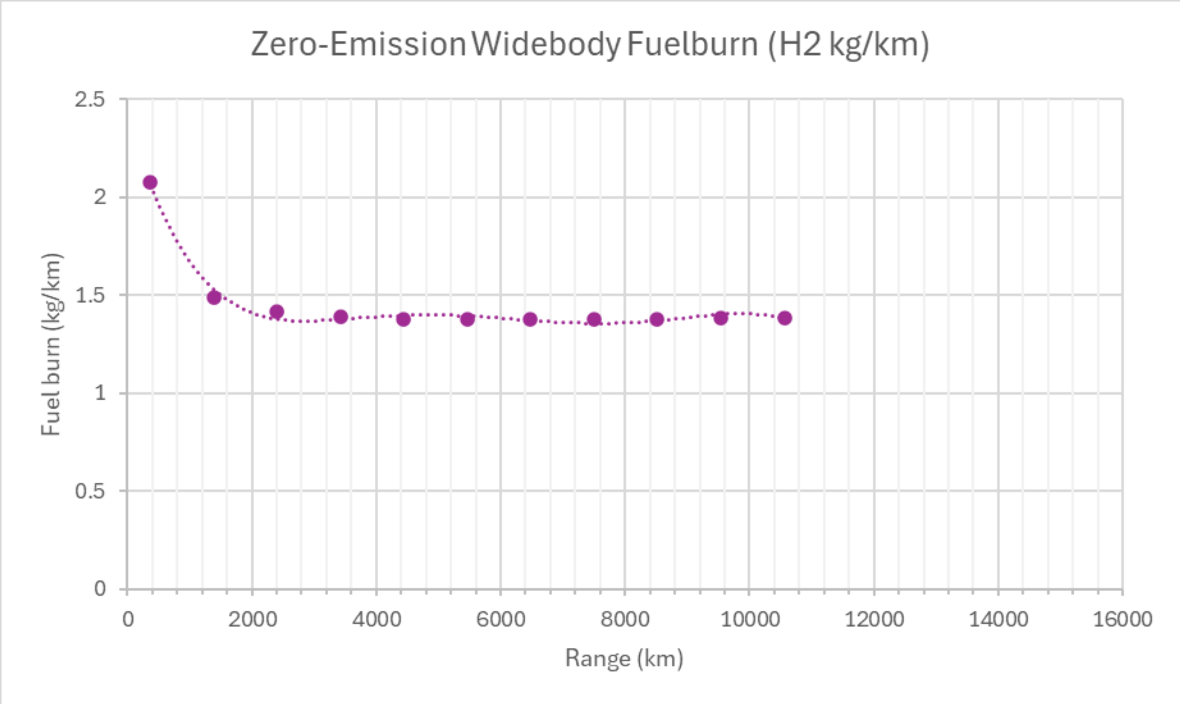


Figure 12: Zero-Emission Widebody Fuel Efficiency

XL Widebody

6.21 Engagement with the ATI concluded that only an ultra-efficient XL widebody was likely across all the scenarios, therefore only the fuel efficiency for an ultra-efficient XL widebody has been estimated.

Ultra-Efficient

6.22 The counterfactual aircraft for future XL Widebody is the 777-9X. A concept XL Widebody was not available within the ATI's aircraft models, which meant alternative approach needed to be taken compared to the other aircraft. Given this type of aircraft will likely serve high emitting long haul routes, DfT opted to be proportionate for this aircraft type and estimate fuel efficiency beyond using manufacturer assumptions as was required with the Commuter aircraft.

6.23 To estimate fuel efficiency the efficiency gain from the 777-300ER is applied to the 777-9X in the ATI modelling suite and applied that gain to the fuel efficiency of the 777-9X.

6.24 The analysis indicates the future XL Widebody will likely be 15% - 25% more efficient than the 777-9X, reflecting the aforementioned decreasing efficiency gains with larger aircraft. As with previous aircraft, the fuel efficiency decreases significantly at first until it plateaus. The lower, plateaued efficiency is likely to be used more frequently in the model due to the nature of the routes this aircraft type will serve

6.25 As with the Widebody above, the source data, EEAs master emissions calculator caps the fuel burn range at 10186km, the DfT modelling suite applies a linear extension in order to obtain fuel burn beyond this distance.

6.26

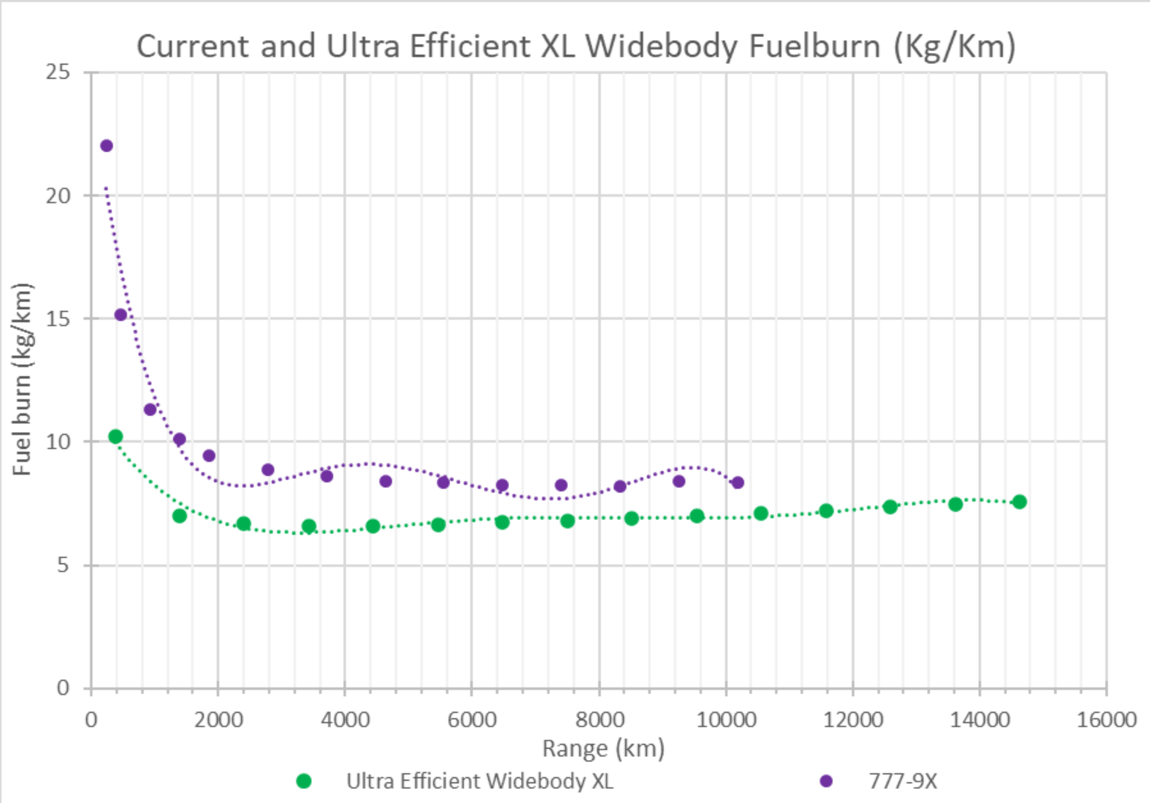


Figure 13: XL Widebody Ultra-Efficient Fuel Efficiency

7. Implications and Next Steps

7.1 The development of aerospace technology is inherently uncertain and is highly dependent on progress made by OEMs, engine manufacturers, and their supply chains. Global standards on aircraft emissions and policy on aviation decarbonisation within individual states and in global agreements provide incentive to drive efficiency in aircraft but technology development is complex and necessarily prioritises safety. This document has presented a series of scenarios and reflected that uncertainty within those scenarios for use in DfT modelling. Nevertheless, there is a need for ongoing monitoring of developments within this area to ensure the assumptions in this paper remain robust and appropriate for modelling use.

8. Appendix: Sensitivity test of 90% load factor assumption

8.1 To convert the ATI payload range estimates into fuel efficiency assumptions for use with DfT's model, DfT has made assumptions on the payload of the aircraft, to do this DfT has assumed a 90% load factor.

8.2 DfT has assumed a 90% load factor because it is in line with the load factor cap for the Scheduled market in the rest of the model. The impact of the load factor assumptions on fuel efficiency has been tested, concluding that fuel efficiency is not sensitive to small changes in load factor.

8.3 Sensitivity tests were undertaken on three aircraft – Regional Turboprop, Narrowbody, XL Widebody.

8.4 DfT has aligned with industry standard assumptions on passenger and luggage weight. Minor changes in the load factor can also be seen as sensitivity tests to this weight assumption. The conclusions of this test are therefore analogous to a sensitivity test on passenger weight.

Regional Turboprop

8.5 Sensitivity tests were undertaken on this aircraft type due to the turboprop technology used to power the aircraft. Sensitivity tests were undertaken with 85%, 50% and 25% load factors, for both ultra-efficient and ZEF variants. 85% was chosen as a realistic estimate of an alternative load factor for this aircraft. 50% and 25% were chosen as extremes for aircraft loading. In reality, it is unlikely this aircraft would be operated with such low load factors. The sensitivity test is presented alongside DfT's 90% assumption.

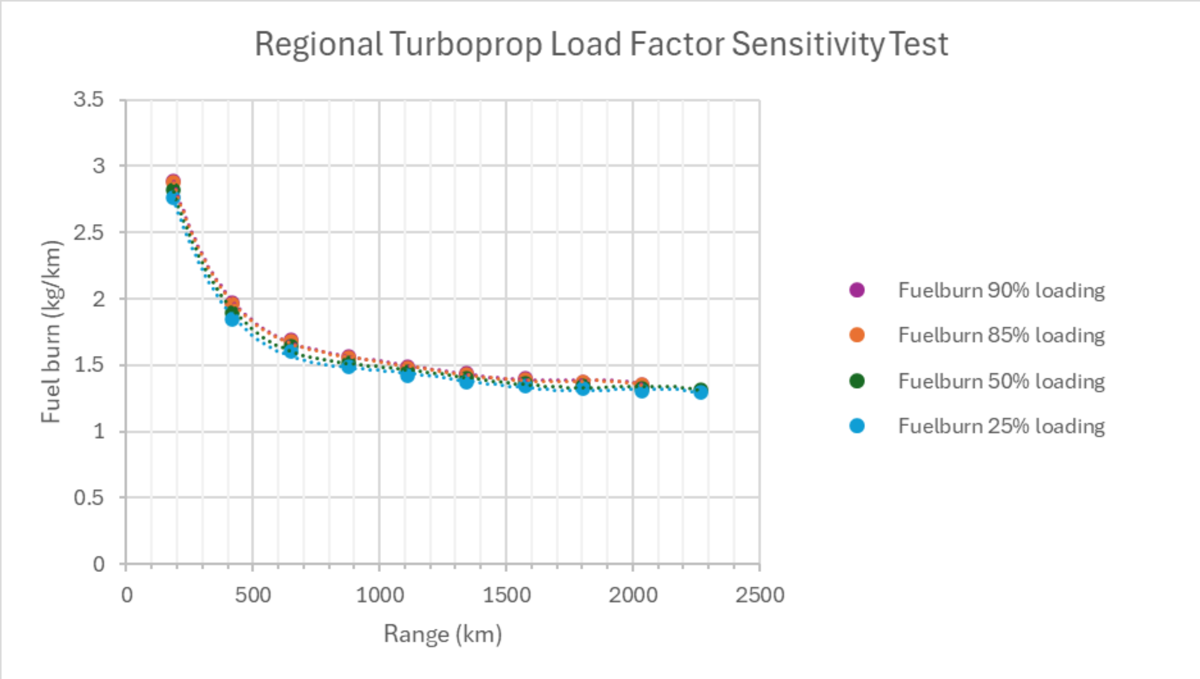


Figure 14: Ultra-Efficient Regional Turboprop Load Factor Sensitivity Test

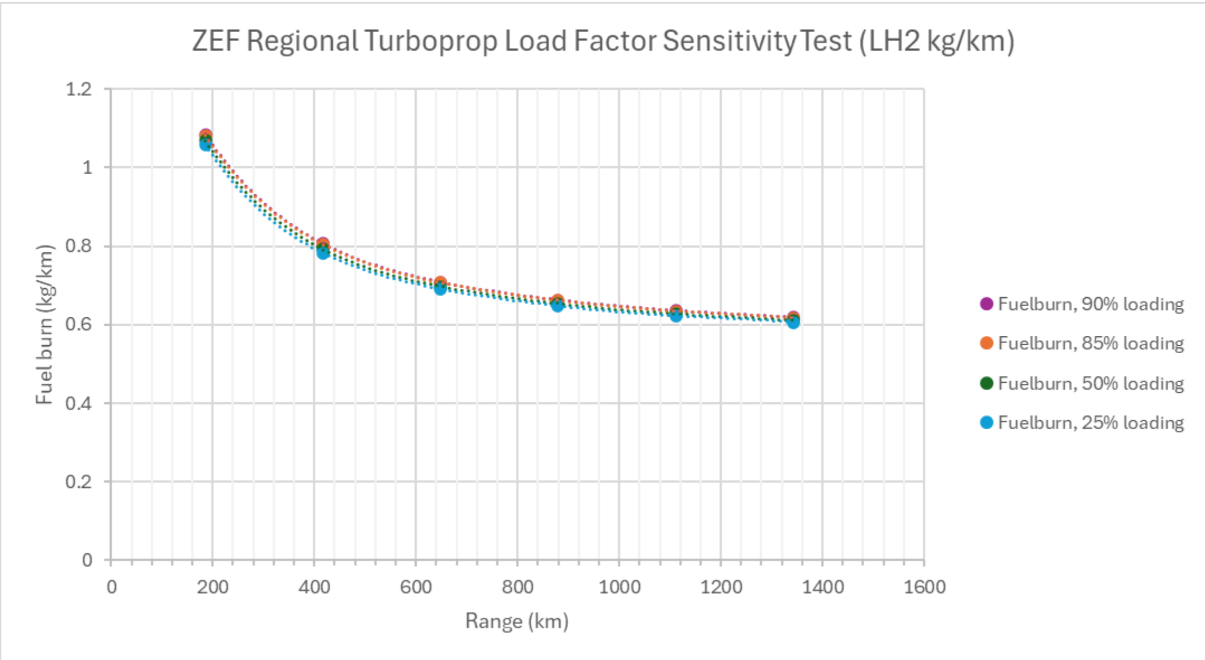


Figure 15: ZEF Regional Turboprop Load Factor Sensitivity Test

8.6 The sensitivity tests indicate the fuel burn for the regional turboprop are not sensitive to aircraft loading. Whilst fuel burn does decrease with smaller loads, which is reflected by more efficient aircraft operation for reduced load factors, the effect is not significant enough to warrant a revision in approach, the minor revisions in fuel burn would be outweighed by noise within the model.

Narrowbody

8.7 The narrowbody was chosen for a sensitivity test because narrowbodies are a significant proportion of the UK fleet. Sensitivity tests were undertaken with 91% and 92% load factors for ultra-efficient and ZEF aircraft; these loads were chosen to illustrate what the impact may be due to minor revisions in loading on the fuel efficiency of the aircraft. The sensitivity tests are presented alongside DfT's 90% assumption.

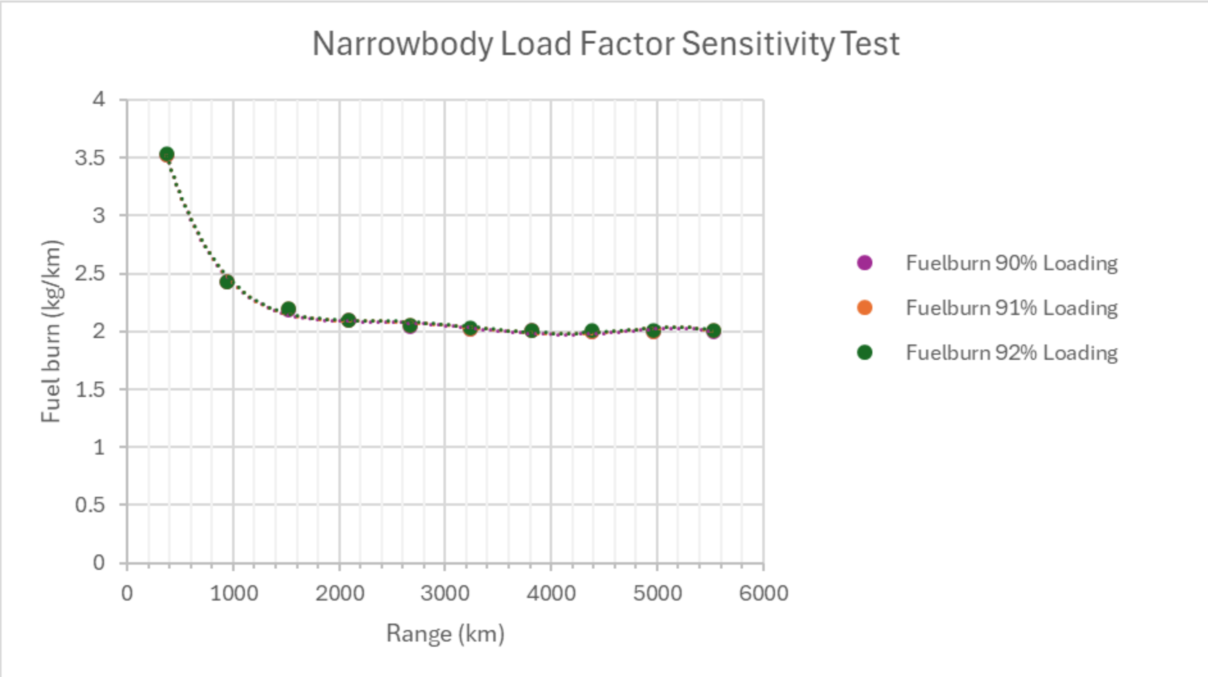


Figure 16: Ultra-Efficient Narrowbody Load Factor Sensitivity Test

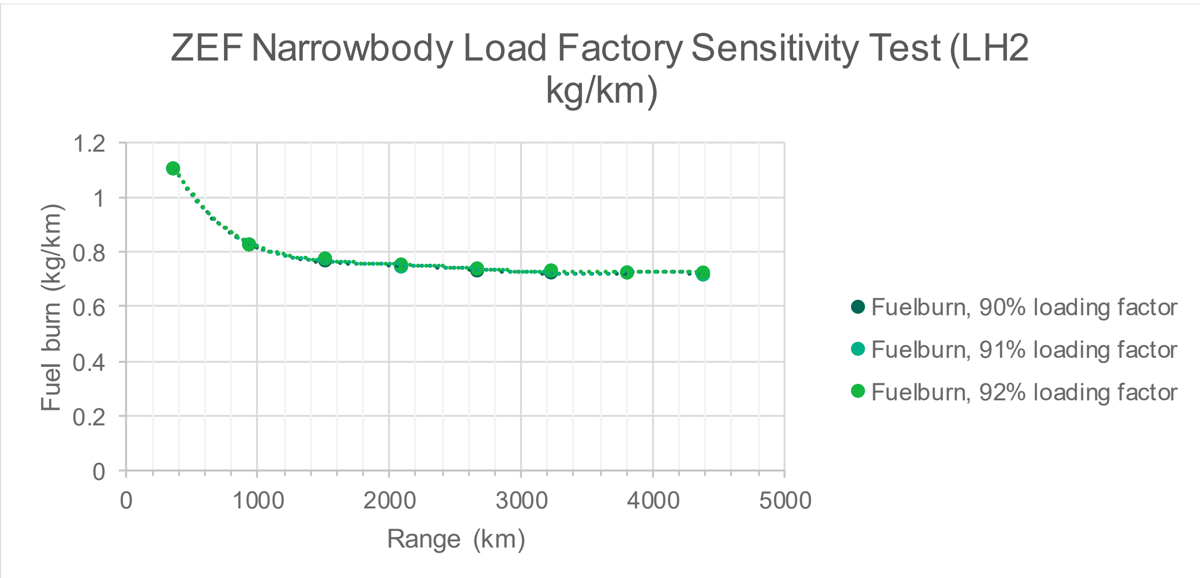


Figure 17: ZEF Narrowbody Load Factor Sensitivity Test

8.8 The sensitivity tests indicate that fuel burn on the narrowbody is not sensitive to minor changes in the load factor. The fuel burn is virtually identical between sensitivity tests – this sensitivity test concludes there is little material benefit to altering load factors for each model run, due to the more likely load factors presented in this test. If DfT was to model such minor revisions in load factors (and if the aviation model enabled us to do so), there would be a negligible impact on emissions.

XL Widebody

8.9 The XL widebody was chosen for a sensitivity test due to the high emitting nature of the routes this aircraft is likely to fly. The narrowbody sensitivity test indicated that a turbofan aircraft is less likely to be sensitive to load factors. A sensitivity test was undertaken with a load factor of 50% to ascertain if a large next generation turbofan aircraft would be more sensitive with extremely low load factors. The sensitivity test is presented alongside DfT's 90% assumption.

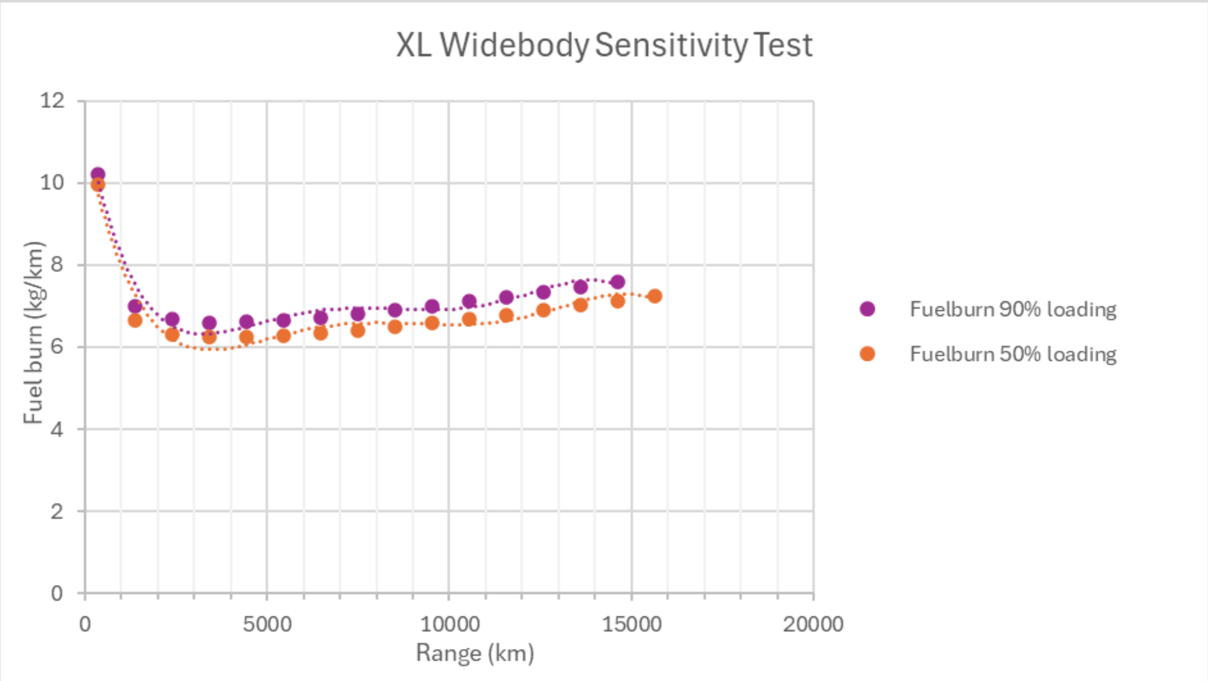


Figure 18: Ultra-Efficient XL Widebody Load Factor Sensitivity Test

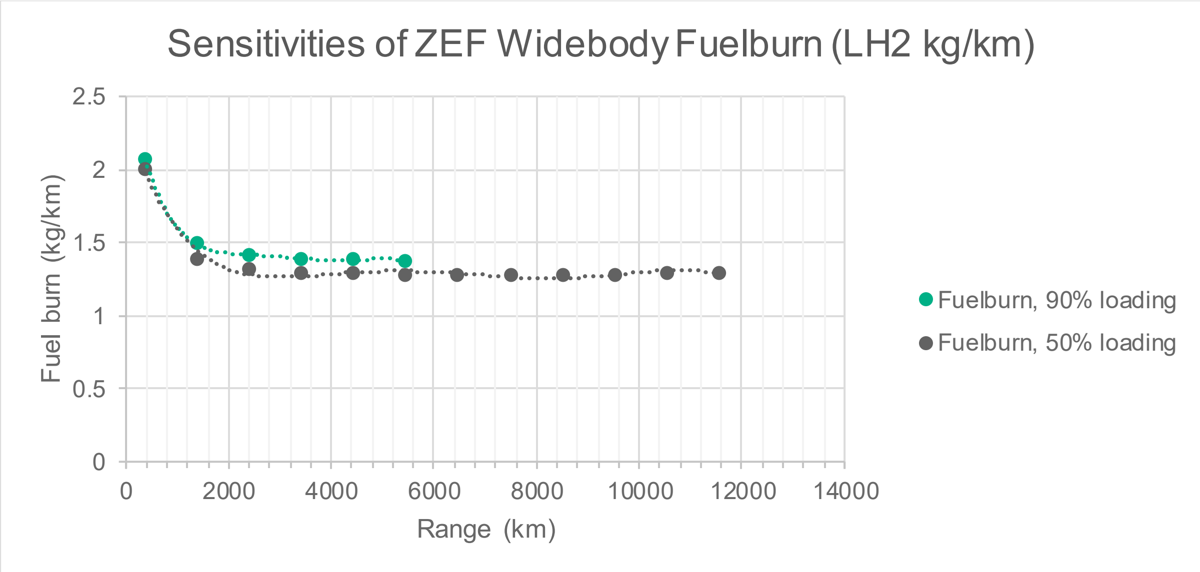


Figure 19: ZEF XL Widebody Load Factor Sensitivity Test

8.10 The sensitivity test indicates the XL widebody fuel performance is likely to see small increases in fuel efficiency with low load factors. It has been concluded that the scale of the result was not enough to warrant a change to the 90% assumption. This is because 50% is a low load factor that is unlikely to be seen in practice. Given load factors are likely to be somewhat higher, it was not deemed proportionate to move away from DfT's assumption.