New Southern Sky - Benefits Evaluation 2023

Version 1.0 January 2024

Disclaimer

Acknowledgements

Contains data sourced from LINZ Data Service (licenced for reuse under CC by 4.0)

Table of Contents

Table of Figures

Table of Tables

Glossary

ADOC	Aircraft Direct Operating Costs
AIP	Aviation Information Publication
APCH	Instrument Approach Procedure
APV	Approach with Vertical Guidance
ATAG	Air Transport Action Group
ATC	Air Traffic Control
CFIT	Controlled Flight Into Terrain
DME	Distance Measuring Equipment
GNSS	Global Navigation Satellite System
IMC	Instrument Meteorological Conditions
IFP	Instrument Flight Procedure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRU	Inertial Reference Unit
MON	Minimum Operating Network
MTOW	Maximum Take-off Weight
NDB	Non-Directional Beacon
NSS	New Southern Sky
PBN	Performance Based Navigation
RNAV	Area Navigation
RNP	Required Navigation Performance
SAF	Sustainable Aviation Fuels
SID	Standard Instrument Departure
STAR	Standard Instrument Arrival
TMA	Terminal Manoeuvring Area
VOR	VHF Omnidirectional Range Beacon

Executive Summary

This report estimates both qualitative and quantitative benefits being delivered by the New Southern Sky (NSS) Performance Based Navigation (PBN) implementation projects. NSS is a 10 year programme of work to enhance New Zealand's aviation infrastructure. It introduced systems and procedures across the aviation domain to implement PBN, and is completed with the final set of PBN instrument flight procedures (IFP) for Hawkes Bay and Gisborne promulgated on 30 November 2023.

PBN promises a range of benefits, including improved passenger safety, airport accessibility, airspace capacity, and flight efficiency with reductions in fuel burn, emissions, aircraft direct operating costs, and savings in passenger time.

PBN improves passenger safety by providing approaches with vertical guidance (APV). Extensive safety studies have shown APV deliver an 8 times safety improvement in the approach phase of flight. Prior to PBN, vertical guidance was available on instrument landing system (ILS) approaches at Auckland, Wellington, Christchurch and Dunedin. PBN provides APV benefits at all locations with a PBN approach.

The improved precision and flexibility of PBN flight paths enables improved airspace capacity and flight efficiency, and improved aerodrome accessibility. Conventional navigation systems require flight paths to run directly to, or from, ground based navigation aids (GBNA). PBN makes use of global satellite navigation systems (GNSS), without necessarily requiring GBNA. PBN flight paths can therefore be located more flexibly, and PBN is more widely and economically available due to the ubiquity of GNSS signals, and the avoided cost of GBNA.

Both controlled and uncontrolled airspace capacity has increased as a result of the improved precision of PBN procedures. Conventional navigation procedures have varying precision. The accuracy generally diminishes with distance from a GBNA. In contrast PBN procedures have a calibrated and constant accuracy. The defined accuracy allows controlled airspace to be minimised, enabling a range of visual flight rules (VFR) and general aviation airspace users to operate while remaining outside of controlled airspace. The outcome reduces ATC workload, thereby increasing the capacity of controlled airspace, and increases the flexibility and ability to operate for VFR operations. The reduced conflict between IFR (particularly scheduled flights) and other aviation activity improves outcomes for both.

Broad availability has improved airport accessibility in adverse weather. NSS has implemented PBN approaches at the 15 ATC controlled airports used by regular public transport. By establishing PBN standards NSS has also enabled many other airports and aircraft operators to implement PBN to support their own operations. PBN approaches have been implemented at 85 aerodromes and heliports including 24 hospitals and medical centres, making the aerodromes accessible in adverse weather (instrument meteorological conditions – IMC) via instrument flight rules (IFR) flights, and delivering APV safety benefits (for suitably equipped aircraft).

Designers have exploited the flexibility of PBN to improve airspace capacity and flight efficiency. En-route flight paths on frequently used routes have been separated into parallel unidirectional routes, creating a 'circular flow' between city pairs. Conflicts between opposite direction traffic are much reduced, enabling flights to more often operate at optimum altitudes, and reducing ATC workload. Both factors increase the route capacity. PBN procedures implemented at the controlled aerodromes have generally shortened the final approach path, reducing flight times for flights from beneficial directions.

This report estimates quantitative savings in fuel burn, emissions, other aircraft direct operating costs (ADOC), the value of passenger time saved, and the number of passengers for whom APV benefits are newly available. Earlier benefit assessment reports in 2014, 2015, 2018, and 2021 estimated benefits from the design intentions of the PBN project prior to implementation.

This report is the first to have the benefit of complete hindsight, and has estimated benefits from the exact 'as built' design details, as used by a complete sample of 937,599 flights in 2015-216 and 2021 – July 2023, extrapolated between 2017 and 2020 using timeseries data for IFR flight numbers, airport passenger numbers, weather, fuel prices and New Zealand dollar exchange rate variations from 2015 onwards.

Future benefits through to the end of the economic life of NSS in 2033 are estimated based on anticipated air travel demand, the ongoing refresh of the airliner fleets, known intentions for aircraft PBN capability improvements, and (optionally) potential emerging use of sustainable aviation fuels (SAF) and introduction of hybrid or battery-electric aircraft indicated by Air New Zealand.

Benefits are estimated by comparing actual outcomes using PBN with the 'counterfactual' – what would have happened absent the PBN infrastructure. Benefits are attributed to NSS where the difference in outcomes is the result of NSS initiatives. The advantageous effects of ATC or pilot interventions that improve upon the PBN outcome, and the disadvantageous effects of air traffic congestion are excluded.

Benefits from NSS were obviously affected by the downturn in aviation during the Covid-19 pandemic. Fluctuating levels of aviation, and global supply chain disruption created a range of effects including dramatic variations in fuel price and passenger load factors at times, along with structural changes to the aircraft fleet and traffic patterns. Fleet fuel efficiency has improved as many airlines have accelerated fleet changes, furloughing older or less fuel efficient aircraft. Schedules and route frequency have also changed. Available data has enabled detailed modelling of these effects.

Geopolitical and environmental risks create greater uncertainty about future events than was assumed in previous benefit estimates. This report bases the baseline 'traditional growth' future scenario on nearer term economic and fiscal forecasts by the New Zealand Treasury, and expansive economic research by Boeing and IATA. In the next two years, growth in domestic aviation activity is expected to be modest in line with constrained domestic consumption, before resuming a moderate growth path. International travel is assumed to continue to recover to 2019 levels by 2026, and grow from there in line with the moderate growth path forecast by Boeing for the Oceania region, and IATA globally. PBN creates a marginal gain for IFR activity. Future benefits can be expected to rise or fall from the estimates depending on the level of aviation activity, as affected by any of the wider risks that may eventuate.

Benefits of NSS are estimated as follows:

Benefit	To Date	Future	Total
Flight Distance Saved (nm)	2,370,000	4,950,000	7,320,000
Flight Time Saved (hours)	6,720	14,700	21,400
Fuel Saved (Tonnes)	9,480	18,200	27,700
CO2 Saved (Tonnes)	30,000	57,600	87,600
Passenger Time Saved (hours)	660,000	1,300,000	2,000,000
Passenger APV	16,000,000	34,000,000	50,000,000
Fuel Saved (NZD 2023)	11,600,000	26,000,000	38,000,000
ADOC Saved (NZD 2023)	19,500,000	31,900,000	51,400,000
Value of Passenger Time (NZD 2023)	15,000,000	28,000,000	43,000,000

'To date' means to the end of July 2023. Benefits to date are less than the normal annual benefits in future, as a result of (a) the staged delivery of PBN implementation at various airports, and (b) the significant downturn during the Covid-19 pandemic. Future benefits increase due to (a) complete PBN implementation, (b) the ability of Air New Zealand ATR72 flights to use the highly advantageous RNP AR approaches from 2026, and (c) the assumed recovery of both domestic and international aviation activity to 2019 levels from about 2026.

NSS benefits are reduced as aircraft fuel consumption and emissions decrease (an improvement). Air New Zealand aspire to use 10% sustainable aviation fuels (SAF) by 2030. CO^2 emissions from burning SAF are assumed to be fully absorbed by the feed stock used to create the fuel, and would not be counted as an NSS benefit. This use of SAF would reduce NSS CO^2 benefits by 2,388 tonnes. The use of hybrid or battery electric aircraft to replace Air New Zealand's Q300 fleet would also reduce fuel and CO^2 savings benefits by about 1%.

1 Introduction

In 2014, the CAA led New Southern Sky (NSS) programme of work began implementing New Zealand's National Airspace and Air Navigation Plan (NAANP). The 10 year programme introduced systems and procedures across the aviation domain to implement Performance Based Navigation (PBN). The plan significantly improves New Zealand's airspace and air navigation system, with a range of safety, economic, environmental and social benefits. The air navigation infrastructure aspects are completed with the commissioning of approach and departure procedures in Hawkes Bay and Gisborne on 30 November 2023.

1.1 Purpose

NSS has regularly updated the assessment of benefits likely to be realised from the NSS body of work. The purpose of this report is to update past and future benefits of the New Southern Sky (NSS) programme initiatives in respect of:

- Safety benefits of approaches with vertical guidance (APV)
- Flight time reduction consequent savings in
    - Fuel burn and aircraft emissions
    - Fuel and aircraft direct operating costs (ADOC)
    - Passenger time
- Improved airport availability and capacity

1.2 Approach

The most recent update to benefits assessment in 2021 outlines possible approaches to future benefits reporting. Options included simply scaling the known benefit mechanisms in line with the changing volume of air traffic, and optionally updating the baseline assumptions to take account of evolutions in the nature of air traffic and differences between earlier assumptions and the 'as-built' navigation infrastructure. This report updates the baseline assumptions.

Earlier NSS benefit assessments were based on a-priori expectations, or the current design intentions, prior to the PBN implementation being completed[1]. The aviation activity baseline was largely that created for the Acuo report of 2018, based on the characteristics of commercial air transport to 2016. That approach was reasonably valid until the onset of the Covid19 pandemic at the end of 2019. This report revises earlier baselines to take account of subsequent changes in flight activity, and design details of the PBN implementation. In particular:

- The 'as-built' PBN navigation infrastructure is complete. It differs from earlier modelling assumptions in some locations;
- The aircraft fleet is more efficient. Increasing use of Airbus A320/A321 'neo', A350 and Boeing 787 jets, and smaller turboprop aircraft on applicable routes has improved the fleet fuel efficiency;
- Airline route frequency has evolved, particularly since the Covid19 pandemic;
- Levels of international tourism and aviation activity have varied widely and rapidly as a consequence of evolving public sentiment and the public health responses to the pandemic;
- Fuel pricing has varied, rapidly at times, as a result of fluctuating demand, and supply chain challenges resulting from the pandemic.

This report is the first to evaluate NSS benefits with retrospective knowledge of the completed 'as-built' PBN system. Where benefits are quantified, the estimates are based on the finalised PBN navigation system design and actual flight data. Benefits have been calculated using a database of 486,120 commercial IFR flight arrivals

[1] An initial economic assessment of the National Airspace and Air Navigation Plan (Castalia, 2014), subsequently updated in 2015, was updated in 2018 and calibrated using actual traffic operations and more detailed PBN design intentions (Acuo, 2018). A subsequent update in 2021 (Mahino Consulting, 2021) re-assessed the 2018 estimates in the light of the actual air traffic volumes to date and the downturn in air traffic resulting from the Covid 19 pandemic, while continuing to use the estimation model based on design intentions as understood in 2018.

at the airports of interest (ATC controlled airports other than military) between January 2021 and July 2023 and the 451,479 equivalent arrivals during calendar years 2015 and 2016. The estimates assess the way in which those flights interact with the PBN navigation infrastructure.

The commentary in the 2017 Acuo report remains relevant:

"Changes associated with PBN form part of a dynamic and interconnected/interdependent system. While obvious to those directly involved with aviation procedures, for others it is worth restating this degree of dependency and interconnection. The existence of global satellite based equipment on aircraft of itself does little of significance to airspace safety or operations. Equipment needs certification, aircrews need training and certification in both equipment and then the various new airspace procedures developed that utilise the enhanced positional accuracy, new airport approach and flight procedures need to be developed and promulgated by air traffic authorities, and airports need to adopt relevant changes, including at times engagement with local communities over potentially changed traffic and noise.

Actually measuring and correctly attributing the observed benefits, the approach adopted in this report, is consequentially challenging."

"Given this complexity and uncertainty, this report has adopted a deliberately conservative approach to the review of costs and benefits, although harnessing big data techniques and modelling to incorporate a wide data set of actual measurements of physical flight operations changes in New Zealand. Consequently the benefits identified represent a robust conservative estimate of quantifiable benefits from observed changes."[2]

1.3 Acknowledgements

Several stakeholders have contributed background information. In particular, Aeropath and Airways New Zealand have made detailed navigation system and flight data available. This has enabled the quantified benefit estimates to be based on actual outcomes: the complete 'as-built' navigation system, including the Hawkes Bay and Gisborne area PBN navigation system commissioned at the end of November 2023; detailed data from previous assessments; actual flight activity[3]; and air traffic volume and weather data for the preceding decade.

[2] (Acuo, 2018, p1)

[3] The supplied flight data excludes military and some other operations. The remaining data appears comprehesive. Monthly movement numbers average within 0.3% of Airways reported total movement numbers.

2 Benefit Enablers

2.1 Performance Based Navigation

The benefits of PBN arise either directly from the technical features of PBN navigation, or from the more effective flight paths enabled by the more flexible design potential of PBN.

The most significant PBN enablers for quantifiable benefits are:

- Approaches with vertical guidance improve flight safety;
- Shorter approaches to airports reduce flight times, reducing fuel burn, emissions, and aircraft direct operating costs (ADOC) and save passenger time;
- Reduced minimum altitudes on approach reduce flight diversions in adverse weather.

Other benefits include:

- PBN instrument procedures based on GNSS are more cost-effective to implement. PBN is therefore more widely available, improving access to airports in adverse weather and increasing the resilience of air transport;
- Helicopter specific routes and approach procedures to hospitals improve rescue and medivac service availability;
- Continuous descent profiles enable more efficient flight, reducing fuel burn and emissions;
- Circular flows, which separate otherwise conflicting air traffic, increase airspace capacity both around airports and enroute;
- Improved navigation precision:
    - Increases the predictability of air traffic enabling improved air traffic flow management,
    - Allows controlled airspace to be minimised, benefiting aviators in uncontrolled airspace.

2.2 PBN Features and Capabilities

2.2.1 Approaches with Vertical Guidance

PBN approaches to runways improve safety by providing approaches vertical guidance (APV). Safety studies have shown that APV approaches significantly reduce risk during the approach and landing phases of flight. The safety benefits of PBN were one of the primary drivers for ICAO requiring member states to implement PBN.

Several safety studies in the 1990s analysed the root causes of controlled flight into terrain (CFIT) accidents in the approach and landing phases of flight[4]. CFIT accidents occur when the aircraft remains under control, but the pilots have lost situation awareness by becoming distracted, disoriented, or otherwise; in situations where insufficient safeguards exist to ensure their continuing ability to navigate correctly. Based on a large number of accident histories, the research found that runway aligned approaches with lateral guidance were 25 times safer than approaches made by circling the airport to line up with the runway visually. Approaches with vertical guidance were 8 times safer again.

Recognising these safety benefits, the International Civil Aviation Organisation (ICAO) passed resolutions requiring member states to implement PBN[5]. Aligned with these resolutions, the New Zealand PBN implementation has followed the New Southern Sky Concept of Operations which calls for all instrument approaches to runways at controlled aerodromes to use PBN approaches with vertical guidance (Civil Aviation Authority of New Zealand, 2018).

---

[4] As an example, (Khatwa & Helmreich, 1999)

[5] The 36th assembly of ICAO passed resolution A36-23 (ICAO, 2007) calling for States to plan and implement APV for all instrument runway ends, either as the primary approach or a back-up for precision approaches, by 2016. The 37th assembly passed resolution A37-11, recognising that APV may not be practicable for all States and locations and authorised PBN approaches without APV as an alternative(ICAO, 2013).

Prior to PBN implementation, vertical guidance was provided only for runways with instrument landing systems (ILS) (Auckland, Wellington, Christchurch, and Dunedin). The benefits of vertical guidance are delivered by PBN for any aerodrome approach that previously lacked ILS.

2.2.2 Flexibility in Instrument Procedure Design

Flight efficiency can be improved using PBN, by taking advantage of increased flexibility in instrument flight procedure (IFP) design. The pre-existing 'conventional' navigation system restricts flight paths to lines that are directly to, or from ground based navigation aids (GBNA). PBN enables flight paths to be more flexibly located. Where practicable the PBN system has used this flexibility to create designs which:

- Reduce flight times by creating shorter approaches to airports
- Reduce air traffic congestion by separating conflicting flows of traffic

2.2.3 Continuous Descent Operations (CDO)

Flight efficiency is also improved by the nature of PBN navigation during descent. Conventional navigation methods often involve segments of level flight during descent. In contrast, PBN techniques support 'continuous descent operations' (CDO). To achieve CDO, the aircraft navigation system computes a low-power continuously descending trajectory along the IFP flight path, to arrive at the correct height and speed for final approach without using powered level flight during the descent. Level flight at lower altitudes can be several times more fuel intensive than in cruise. Continuous descent operations reduce fuel consumption, with savings in costs and aircraft emissions. Jet aircraft have generally had a form of area navigation (RNAV) dating from prior to PBN standardisation, including CDO capability. New CDO benefits from PBN are mainly realised at domestic regional airports and for turboprop operations.

2.2.4 Use of Global Navigation Satellite Systems (GNSS)

The benefits of PBN are more widely available as a result of PBN's ability to use GNSS. Conventional instrument flight navigation relies on ground based navigation aids (GBNA). PBN navigation procedures using GNSS enable instrument flight without necessarily needing ground based navigation aids[6].

PBN procedures can therefore be implemented cost-effectively at locations where traffic levels may not justify installing ground based navigation aids. PBN approach and departure procedures have been implemented at a large number of landing sites, including not only airports but also hospitals and medical facilities.

PBN navigation capability is also available to a wider range of aircraft. Sophisticated PBN navigation systems, used on larger commercial aircraft, are able to navigate using all available 'sensors' (including receivers for ground based navigation aids, on board inertial reference units (IRU), and GNSS). GNSS-only PBN navigation systems are available at lower prices and in lighter, smaller packages suitable for installation in simpler aircraft. A wide range of aircraft, including light aircraft and helicopters, have installed PBN capability.

2.2.5 Improved Navigation Precision

The higher precision of PBN navigation enables more efficient use of airspace, and improved access to airports in difficult terrain.

Whereas conventional navigation methods have varying precision depending on the type of GBNA and its distance from the aircraft, the navigation precision of PBN is known and constant along the defined PBN flight path. Aircraft using PBN are contained within statistically understood bounds around the nominal navigation procedure centreline. As a result, controlled airspace can be reduced to only that needed to safely contain PBN flights, enlarging the volume available for general and recreational aviation operating outside controlled airspace.

[6] Some restrictions do apply. In the event of loss of GNSS based navigation capability, due to either aircraft or external factors, operators are required to have an alternative means of navigation that does not rely on GNSS, to continue to a safe landing (Civil Aviation Authority of New Zealand, 2021). In practice, for aircraft unable to continue using visual flight rules (VFR), this means that a minimum operating network (MON) of ground based navigation aids is required for contingency purposes, and aircraft need to retain some conventional radio navigation means.

PBN approaches with required navigation performance - authorisation required (RNP AR) further improve airport accessibility and flight efficiency. RNP AR procedures have the most precise navigation tolerances of the PBN procedures and can include curved segments. The higher precision of RNP AR enables safer approaches through difficult terrain, to much lower minimum altitudes. RNP AR procedures are tailored for the location, aircraft types and operators using the runway. They are only available to approved operators as they require additional capability of the aircraft and flight crew. Maintaining that capability imposes additional requirements on the operator's organisation and procedures.

Benefits can include much reduced flight path length, and improved access to airports in unfavourable weather (due to the lower minimum descent height) or through difficult terrain (Queenstown) with a consequent reduced probability of flights needing to divert to alternative airports.

2.1 Value Drivers

The PBN navigation infrastructure consists of a network of air routes for enroute navigation, approach procedures for runways or helipads, and standard arrival and departure procedures connecting aerodromes with the enroute network.

A flight using the PBN navigation system follows a sequence of applicable procedures:

- departing via a standard instrument departure (SID), to connect with -
- (a sequence of) routes leading to the destination, transitioning to -
- the standard instrument arrival (STAR), leading from the route to -
- the final approach procedure (RNP APCH), or an alternative RNP AR approach to landing.

The benefits of PBN are driven by outcomes resulting from either the technical capabilities of PBN procedures, or features of their design. The majority of benefits result from features of STAR and approach procedures.

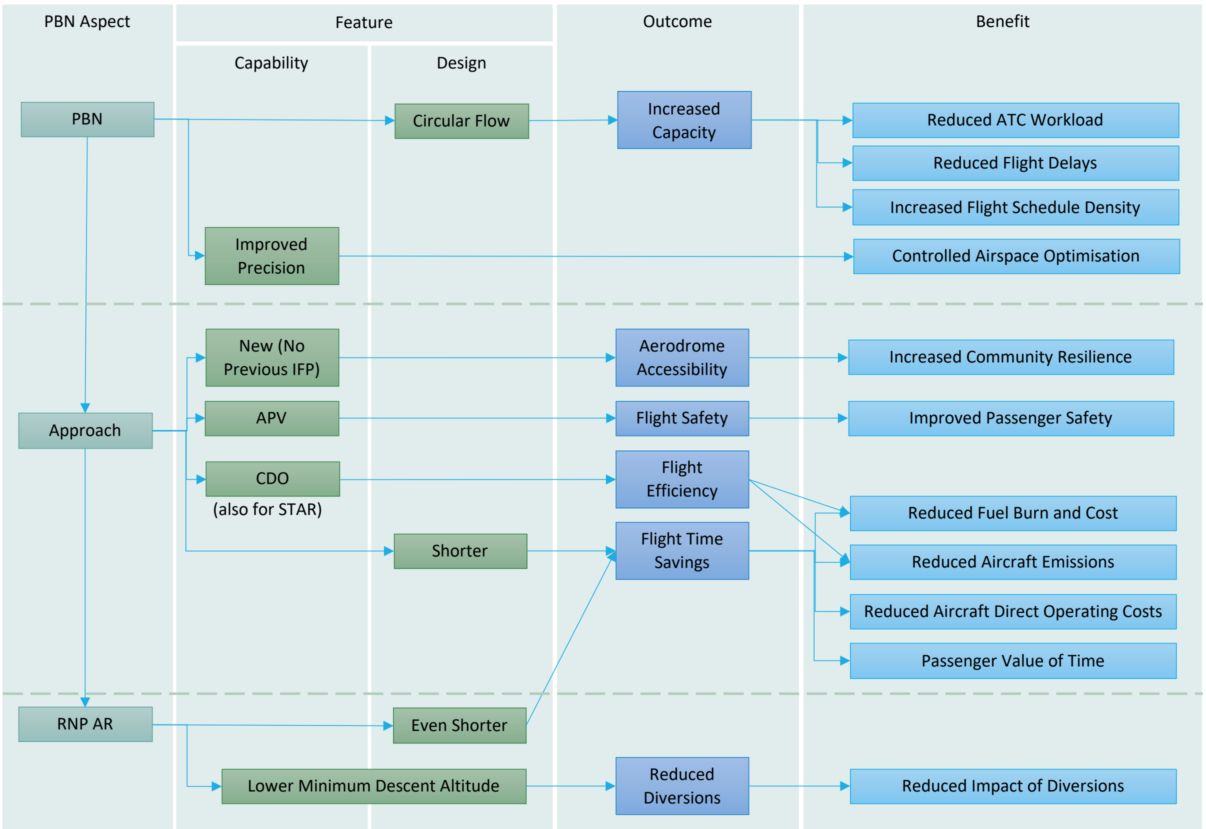


Figure 1 PBN Value Chain

2.2 Benefits Attribution to NSS

This report assesses the net effect on flight operations of the beneficial features of PBN, compared with the counterfactual: what would happen had PBN not been implemented. Results are quantified where both the PBN outcome and the counterfactual can be reasonably estimated.

Benefits are attributed to NSS initiatives where the effects create a systematic baseline performance improvement resulting from actions taken by NSS. From a high level perspective, these are:

- Establishing PBN. The advent of PBN operations has enabled multiple stakeholders to implement user specific PBN initiatives such as approach procedures at private aerodromes and medical facilities, or simply expand the range of operations available to their aircraft. These effects are described qualitatively.
- Implementing PBN navigation infrastructure for the national enroute system, and for approach and departure procedures at controlled aerodromes. This infrastructure delivers the flight safety and efficiency advantages and the benefits that flow from them. These benefits are quantified where practicable.

Confounding factors affect the extent to which the benefits of PBN arrival and approach procedures can be fully realised.

In times of higher density traffic, queuing prevents aircraft from simply following the IFP. Affected aircraft must delay behind the flights ahead and be vectored to the approach by ATC under surveillance control. The benefits of PBN become systematically less obtainable as traffic density increases. The ATC intervention benefits overall flight efficiency by maximising the runway throughput, and therefore minimising the overall flight delays. However, those efficiency benefits of ATC action are attributable to ATC. The benefits (to each individual flight) of the PBN procedures are lost to some extent in the interests of overall efficiency.

Conversely, tactical intervention by ATC or pilots may improve upon the PBN baseline performance. To reduce flight time, ATC or pilots may opportunistically select a direct route bypassing parts of the PBN procedure. For approach procedures, there may be a trade-off in that the benefits of APV may not be realised, depending on whether the flight transitions to a visual arrival or continues with the instrument approach at some point. Nonetheless, the PBN procedure could have been used. It provides a baseline benefit, capping flight costs to the default case, and providing the opportunity for APV, whether or not is used. The net result for the flight is the sum of the PBN benefit and any changes created by the tactical intervention. In these instances, the PBN component of the result is attributed to NSS. Any further benefit the flight might obtain, over and above the default case of using the PBN procedure, would be attributable to the intervention.

3 Realising Benefits

3.1 Aircraft PBN Capability

For flights, realising PBN benefits depends upon the flight having the technical capability required to use the relevant PBN features. The technical requirements (and, depending on aircraft equipment levels, aircraft capability may) differ for operations in each of:

- Enroute
- Terminal (SIDs and STARs)
- Approach (RNP APCH)
- RNP AR

Appendix A.1 tabulates the variety of aircraft capabilities for the 1188 aircraft most frequently flying IFR approaches to any destination in New Zealand during the sample period from 2021 through July 2023.

Almost all PBN equipped aircraft have the capability to operate in the terminal and enroute phases of flight. PBN equipped aircraft participate in creating the benefits of traffic circular flows, increasing airspace and airport capacity. The more predictable flight paths also assist the ATC process to better manage traffic flows.

The benefits obtained in the approach phase vary with the capability level of the aircraft.

- All aircraft with APCH functions have lateral navigation (LNAV) capability. The aircraft can follow the path of the procedure to the required accuracy and obtain the benefits of shorter approach paths.
- Optionally, aircraft can also have vertical navigation (VNAV) capability. Aircraft with VNAV capability obtain vertical guidance and gain the efficiency benefits of continuous descent approaches and the safety benefits of APV.
- Aircraft with RNP AR capability gain the benefit of lower approach minima (with reduced chance of diverting to an alternate airport in adverse weather), even shorter approaches in several locations, and more predictable access specifically to Queenstown airport through mountainous terrain.

For aircraft making approaches at ATC controlled airports (the majority of IFR flights):

- There is an almost complete uptake of PBN across all larger aircraft or those carrying passengers as a service, and 90% of light aircraft which operate IFR.
- Approach and VNAV capability vary. Almost all PBN equipped aircraft in the commercial jet, larger turboprop and business jet, and helicopter categories, and just over half of light aircraft have APCH capability. Almost all larger aircraft and just under half of helicopters have VNAV capability.
- RNP AR capability exists where operators require or value it. All RNP AR capable aircraft have VNAV capability[7].

Aircraft Class	Number of Aircraft	Number of Arrivals	PBN % of Aircraft	Capability (% of PBN)		
				APCH	VNAV	RNP AR
Turboprop	63	259586	95	100	87	48
Narrow Body Jet	168	138801	100	98	92	79
Light Turboprop	49	54005	96	74	30	
Heavy Jet	495	26477	100	100	97	47
Light Aircraft	154	17436	90	61	2.9	
Business Jet	73	4388	100	92	81	4.1
Light Business Jet	10	2618	100	100	20	
Helicopter	11	2747	100	100	45	

Table 1 Aircraft PBN Capability - IFR Arrivals at Controlled Airports

[7] The tables above and in Appendix 1 indicate only the aircraft component of RNP AR capability. The RNP AR function also requires a certificated RNP AR rated flight crew to operate the aircraft. Quantified benefits of RNP AR are only included for flights where the aircraft's RNP AR capability is actually used.

3.2 PBN Implementation

3.2.1 PBN at Uncontrolled Aerodromes

The advent of authorised standards for PBN implementation has created a platform for various operators to implement PBN navigation infrastructure supporting their operations. The NSS body of work created PBN infrastructure at controlled airports. Other aerodrome or aircraft operators have substantially expanded the PBN navigation network.

PBN approach procedures have been implemented at many uncontrolled aerodromes, enabling access to the destination in instrument meteorological conditions (IMC), and with the benefits of APV for suitably equipped aircraft. A subset of these have also implemented STAR procedures connecting the aerodrome to the national enroute network, enabling reliable access to the aerodrome from controlled airspace or enroute flight in IMC.

Notably, 24 hospitals or medical centres have implemented PBN approaches allowing more reliable air transport and Medivac services in adverse weather. A number of supporting air routes have been established specifically for enroute helicopter use.

Appendix A.2 lists the PBN implementation status at aerodromes published in the New Zealand Aviation Information Publication (AIP). In broad categories, PBN implementation status and usage is as follows (flight totals cover the 31 months from January 2021):

Aerodrome Category	# with APV	# with STAR	# IFR Arrivals	# APV arrivals
Aerodromes with scheduled air services	32	28	125653	78042
Hospitals and Medical Centres	24	15	2870	310
Other Aerodromes	21	14	7139	503
Other Heliports	8	6	56	6

Table 2 PBN Implementation at Uncontrolled Aerodromes

3.2.2 PBN Implementation at Controlled Aerodromes

3.2.2.1 Implementation Dates

PBN procedure implementation is completed with the activation of new procedures in Hawkes Bay and Gisborne on 30 November 2023. The implementation at these locations was deferred during the Covid-19 pandemic until future demand and the value of implementing PBN became more clear.

Although the implementation has been made in stages at several locations, benefits arising from PBN are attributed to NSS from the final date when PBN is fully implemented for each aerodrome.

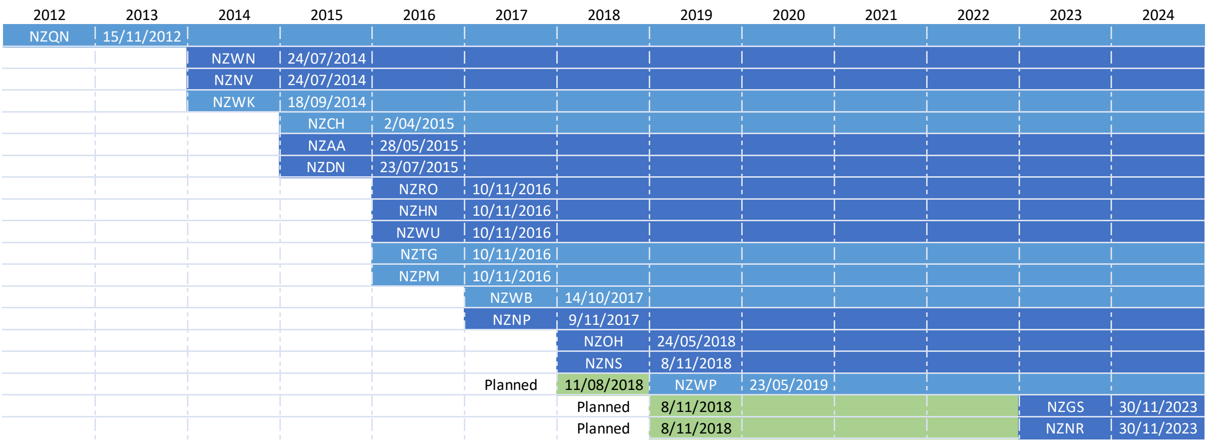


Figure 2 Aerodrome PBN Implementation Dates

3.2.2.2 Shorter Approaches

RNP APCH approaches have been implemented at many, but not all, runways. In most cases, they reduce the flight path length for inbound flights. Inbound flights on the shorter procedures save flight time, with consequent savings in fuel, emissions, passenger time, and aircraft direct operating costs (ADOC).

Where practicable, the PBN designs use some variation of the standard ICAO 'T-Bar' template design for PBN approaches. The design leads aircraft from various directions to a point more or less on the extended centreline of the runway, from where the final approach is made. Aircraft join the procedure at an initial approach fix (IAF) best connected to their inbound flight path, and follow the procedure to the runway via intermediate fixes (IF) if any, and the final approach fix (FAF), usually in line with the runway.

Conventional navigation procedures also connect inbound routes to the final approach, using various methods related to the ground based navigation aids on which the approach is based. Both conventional and PBN instrument approaches tend to be somewhat indirect; manoeuvring the aircraft to line up with the start of the final approach path.

In most cases, the RNP APCH approaches have a shorter final approach leg than the conventional navigation system approach to the same runway. Shorter finals have the general effect of moving the pre-final manoeuvring part of the IFR procedures toward the runway.

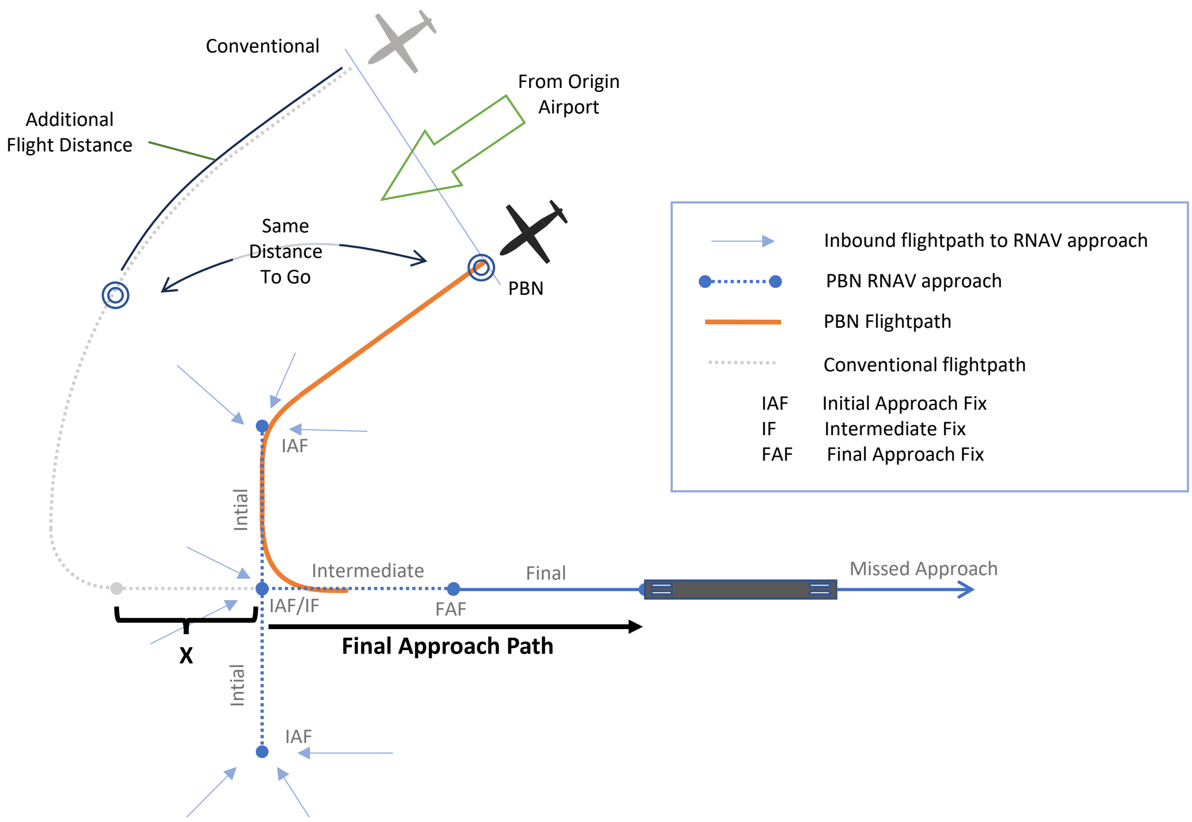


Figure 3 PBN vs Conventional Approach Paths

The flight path reduction for each runway therefore depends on the difference in final approach path length between the conventional navigation procedure and the PBN alternative ('X', Figure 3). For RNP APCH approaches, where savings exist, the final approach is generally shorter by between 2 nm and 4 nm.

The benefit of a shorter approach varies depending on the direction from which arriving flights come. Flights arriving from downwind fly straight in, directly toward the runway, and obtain no advantage. On the other hand, flights arriving from upwind fly past the airport and turn back to line up with the final approach. These flights save twice – with a shorter downwind flight to the start of the final approach, as well as a shorter final approach.

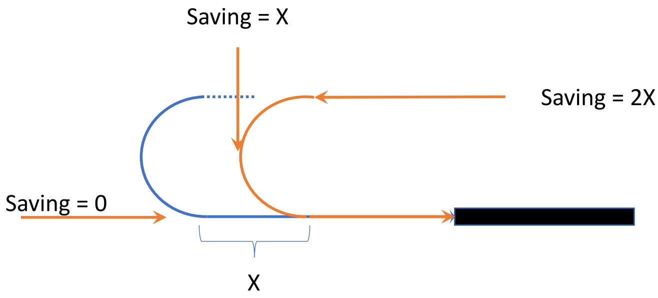


Figure 4 Benefits of Shorter Approaches Depend on Arrival Direction

Approaches using RNP AR tend to be shorter, and in some cases substantially shorter, than the alternative. In effect they create a short-cut from the normal PBN approach, saving additional track miles. As an example, flights using the RNP AR approach to Palmerston North RWY 25 save an additional 19nm for flights from the north, and about 17nm for flights from the south, compared with using the default PBN approach for the route.

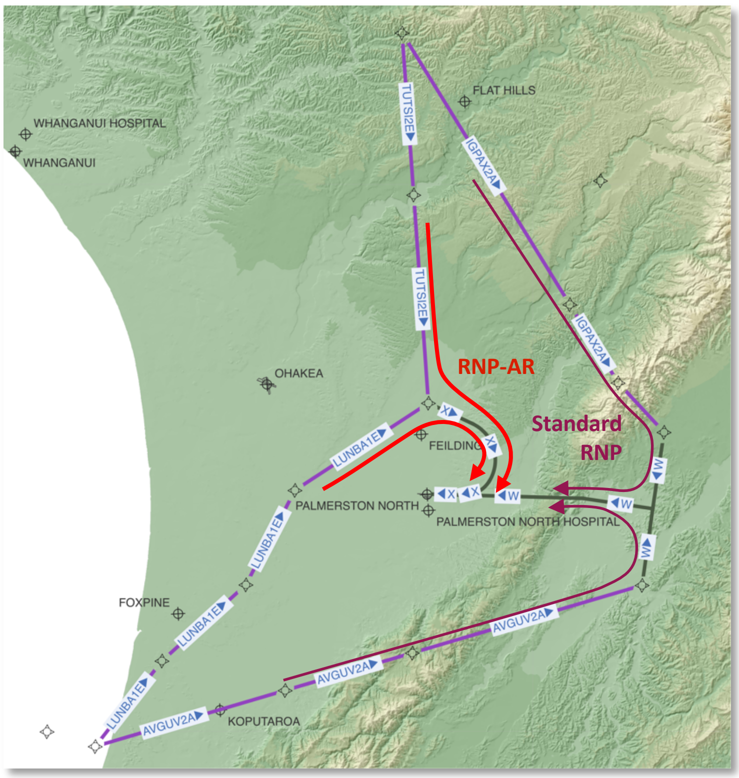


Figure 5 RNP and RNP-AR approaches to Palmerston North Runway 25 Compared

3.2.2.3 Variation from Earlier Modelling Assumptions

Previous benefits modelling assumed general final approach path lengths, based on project intentions prior to PBN designs being finalised. The estimates assumed a standard 8 nm PBN final approach, reduced from 10 nm for the conventional approach at most runways, with exceptions in Wellington and Christchurch for RNP AR arrivals from some directions, and for the east/west runway 11/29 at Christchurch where no previous instrument approach existed.

Terrain and other constraints have led to PBN designs which differ from these earlier assumptions at most locations. Additional complexity exists for approaches at some airports, where approaches for specific traffic flows from some directions join the final approach at various distances, including more than one available option for some routes.

For airports where PBN (RNP APCH) approaches from all directions have a common final approach path, savings compared to the final approach for conventional navigation are:

Airport	Runways	Reduction (nm)	Remarks
Invercargill	All	2.0	
Dunedin	03	-1.7	Terrain prevents joining a shorter final from the side. The PBN approach commences further from the runway than the conventional approach using Berridale NDB.
	21	1.2	Terrain prevents joining a shorter final from the side
Woodbourne	07	Not available	Terrain prevents a standard straight-in approach.
	24	0	PBN approach commences from the same waypoint as the conventional navigation approach.
Wellington	All	0	PBN final approaches commence at the same waypoints as convention navigation approaches.
Palmerston North	07	4	PBN final approach is the 'template' 8nm, however conventional approaches (VOR/DME) commence from 12nm.
	24	0	Terrain requires a PBN final approach starting at the same waypoint as for conventional navigation.
New Plymouth	All	2.0	
Gisborne	14	1.4	Terrain constrained
	32	2.0	
Rotorua	18	0.6	
	36	0.2	
Tauranga	All	2.0	
Hamilton	All	4.0	PBN final approach is the 'template' 8nm, however conventional approaches are 12nm.

Table 3 RNP APCH Final Approach Distance Reduction Summary

For Auckland, Wellington, and Woodbourne, RNP APCH approaches begin at the same distance from the runway as conventional approaches. All flight path savings at Auckland and Wellington arise from the use of RNP AR approaches.

Flight path shortening is not applicable at Queenstown. Both the conventional and PBN approaches are constrained by terrain, and somewhat indirect.

PBN approaches at Christchurch join final on the runway centreline at various distances. The approaches are specific to selected inbound routes in each case.

For runway 20 (Figure 6), flights join final at

- 12nm for flights from the north, and east, and international flights from the north and west
- 8nm for flights from the south and optionally, on Australian routes from Sydney or Brisbane
- 3nm for RNP AR approaches from the south or west

Approaches to runway 02 follow a similar pattern. Flights join final at:

- 12nm for flights from the south, west, and northwest
- 8nm for flights from the north and east, and optionally from Australian routes via Sydney or Brisbane
- Various shorter distances for RNP AR arrivals from the north, east and northern Australian routes

Where RNP AR approaches have been implemented, they usually form an alternative path to a shorter final from a starting point in common with the standard RNP APCH approach. In effect, a short cut. Exceptions to this generalisation are the RNP AR approaches to the 'Northwest' runway 29 at Christchurch, where only RNP AR approaches have been implemented, as terrain prevents a longer, standard, RNP APCH straight in approach, and Queenstown where the approach paths are entirely constrained by terrain and follow similar paths whether RNP APCH or RNP AR.

The shortcut distance savings vary by location and can be substantial. Savings are typically between 6 and 12 nm, except for some RNP AR approaches at Auckland (1.3 to 4.3 nm) and Palmerston North (17 to 19 nm).

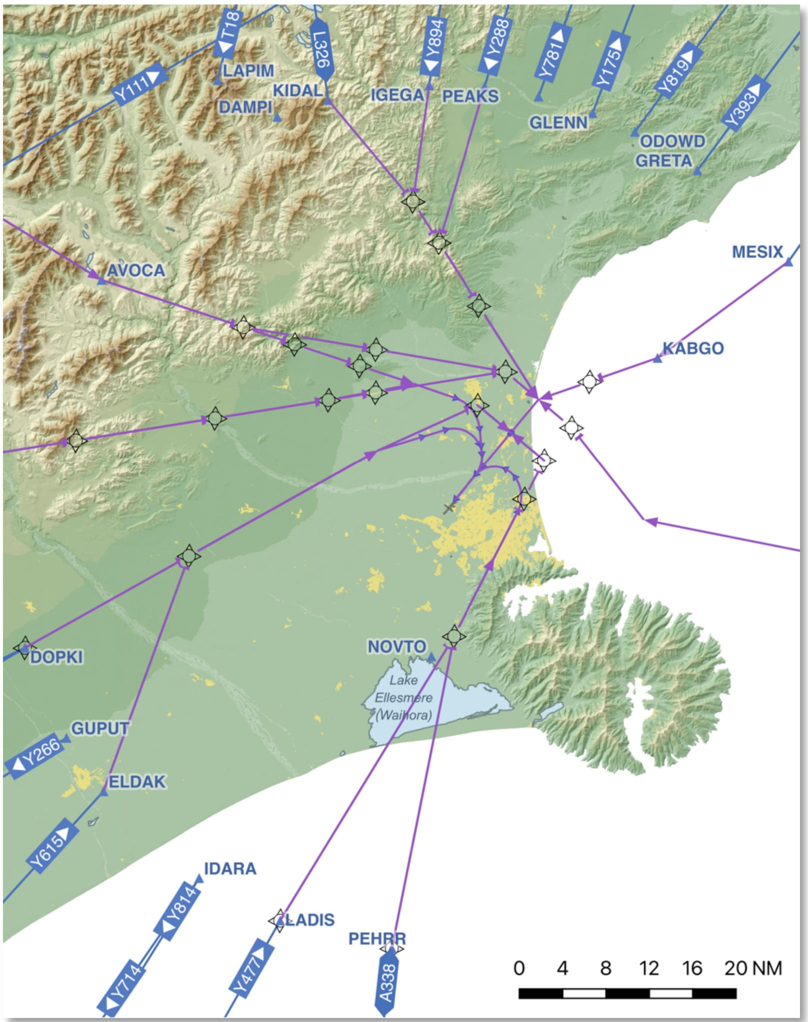


Figure 6 PBN Approaches for Christchurch Runway 20

The shortest RNP AR approaches from the south at Auckland overlay the traditional routes used by pilots to make visual approaches. Prior to PBN, visual approaches were frequently made due to the flight time saving and traffic management advantages. Formalising the approach path using PBN procedures enables the same savings to be made in instrument meteorological conditions (IMC) and at night.

For benefit estimation purposes, the counterfactual to using these PBN approaches, in visual conditions, was normally to fly much the same flight path. Benefits of these approaches are therefore attributed to NSS only when the approaches are flown in IMC, or at night.

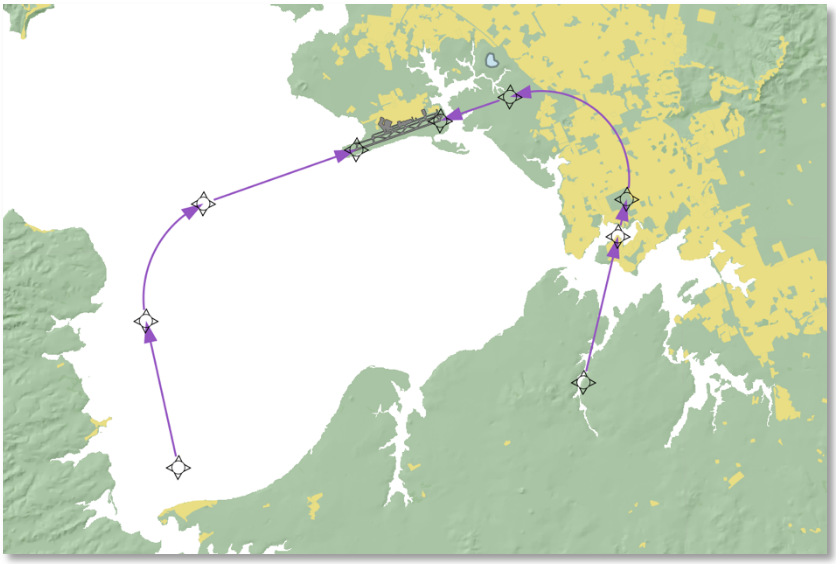


Figure 7 RNP AR 'Y' approaches to Auckland from the South

A complete list of the various approach options for each runway at the ATC attended aerodromes is tabled in Appendix A.5

3.2.2.4 Approaches With Vertical Guidance

All PBN approaches supply vertical guidance to suitably equipped aircraft. The benefits of APV are attributed to NSS for those aircraft with VNAV capability using a PBN approach where there was no prior instrument approach with vertical guidance.

Auckland, Wellington, Christchurch, and Dunedin have long established instrument landing system (ILS) approaches (to the main runway in the case of Christchurch). PBN implementation for these runways may create additional flight efficiency but does not create a new APV benefit. RNP APCH approaches to Christchurch runways 11/29 do provide a new APV capability. APV benefits for approaches to these runways are attributed to NSS.

3.2.3 Enroute

3.2.3.1 Circular Flow

PBN air navigation routes have been added between frequently flown city pairs, to create a ‘circular flow’ using pairs of opposite direction one-way routes. The ‘two lane road’ reduces confliction between opposite direction air traffic, both enroute and during climb out or descent. Benefits include increased airspace capacity by reducing ATC workload, and improved flight efficiency. Aircraft are more frequently able to operate at their optimum altitude, rather than needing to be vertically separated from opposite direction traffic. Figure 8 shows selected circular flow routes, outside of terminal manoeuvring areas (TMA), for selected city pairs including Auckland, Wellington, and the South Island airports with ATC control.

Jet and non-jet traffic are separated on routes arriving into Auckland from the south. This separation is continued into the STARs from the two entry points enabling controllers to defer merging jet with non-jet traffic to the last prudent moment. As the two classes of traffic have differing descent profiles and speeds, deferred merging enables pilots to execute more optimum descents, and controllers to maximise runway throughput by minimising the duration in which jets follow slower aircraft.

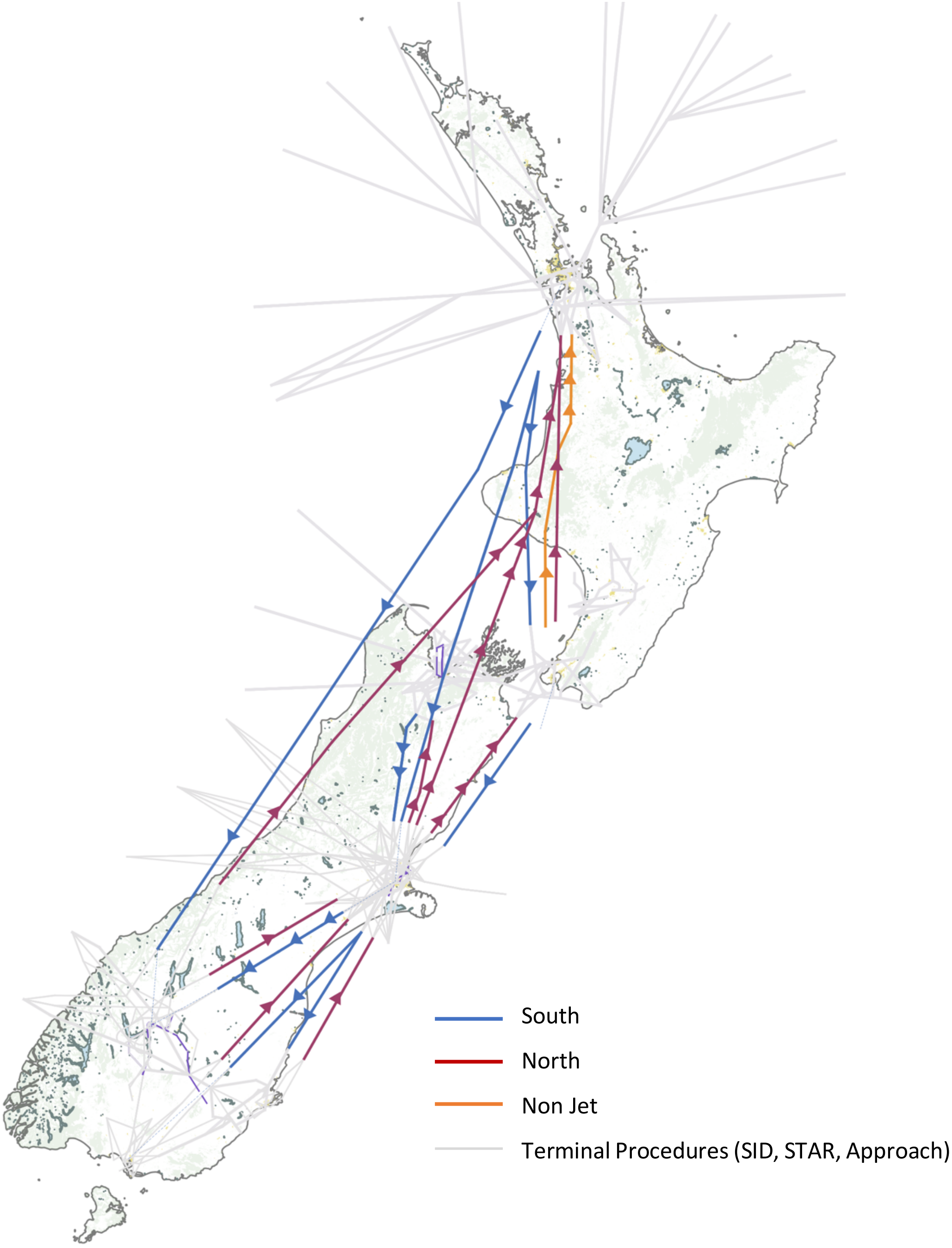


Figure 8 Selected Circular Flow Routes

3.2.4 Departures

Consistent with previous benefits analysis, we have not quantified flight efficiency benefits of PBN for departure or enroute phases of flight. Shorter final approaches consistently deliver a beneficial effect, whereas in other phases of flight, other factors predominate.

The use of departure procedures (and segments of enroute procedures) is variable. For the benefit of operators, when traffic conditions permit, ATC frequently clear aircraft direct toward their destination, including from partway through departure procedures. Direct clearances are opportunistic (although frequent) and depend on traffic conditions at the time. As a result, departure procedures often have their flight efficiency improved upon by ATC practices. The practice may deliver an immediate benefit to the flights concerned. Aircraft reach 'top of climb' closer to their destination, thereby shortening the cruise phase of flight.

This practice can apply whether flights use PBN or conventional navigation. As this benefit is unpredictable but frequent, and delivered to flights whether or not they use PBN, we have not attributed PBN specific benefits to the departure phase of flight.

3.2.5 Airspace

The National Airspace Policy of New Zealand expresses the government's objective of "an efficient, safe, secure, accessible and resilient transport system that supports growth". The policy notes that "private air transport, and recreational aviation activities also make a valuable contribution to the economy." [8]

Well considered airspace design gives effect to this policy. The defined tolerances of PBN procedures enable controlled airspace to be minimised. Benefits include improved flight efficiency and greater access to airspace for uncontrolled air traffic. Revised airspace boundaries that enable VFR flights to operate whilst remaining outside controlled airspace can also reduce ATC workload. Appropriately minimised controlled airspace therefore increases the effective capacity of both controlled and uncontrolled airspace.

To contain flights using conventional navigation in aerodrome terminal areas, controlled airspace has previously been designed around ground based navigation aids so that flights approaching from many directions can remain in controlled airspace while descending toward, or climbing away from the GBNA. The design generally appears as a stack of descending circular floors of decreasing radius and altitude closer to the aerodrome and its associated navigation aids. The airspace required can be large where flights arrive from many directions.

In contrast, airspace containing PBN procedures can be narrowed, within reason, to contain exactly the IFR procedures and the standard navigation tolerance around them, releasing all other airspace for other users. Figure 9 compares controlled airspace around Christchurch with that at Nelson, to the same scale. The airspace south and north of Christchurch is designed in part to contain conventional navigation procedures. The Nelson airspace was deliberately reduced in 2018 to the minimum required to contain the PBN IFR procedures.

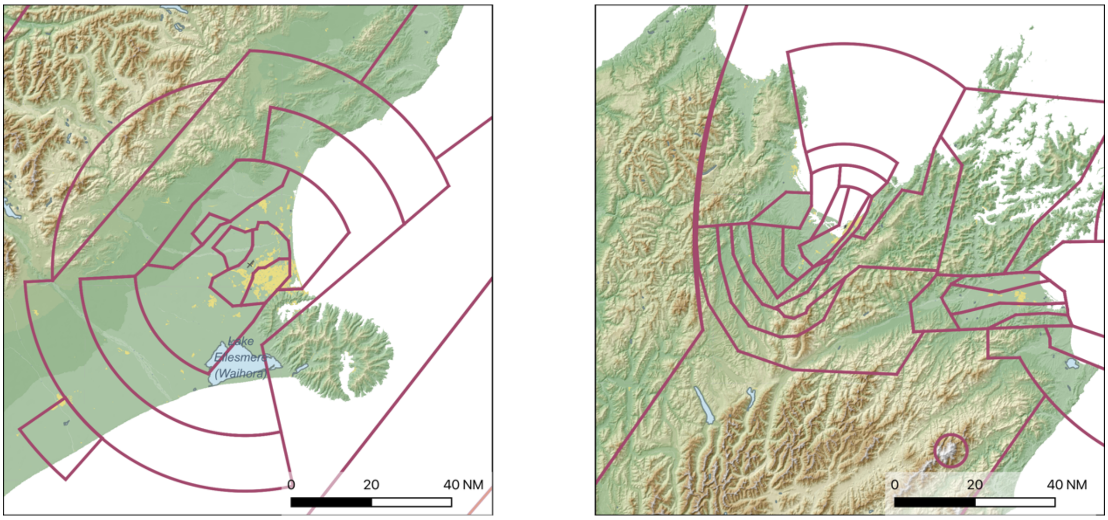


Figure 9 Controlled Airspace - Christchurch and Nelson

The minimalist design at Nelson conveniently separates a range of aviation activity in the region from IFR procedures used by scheduled air services to Nelson, to the mutual benefit of both. In particular, the design removed designated controlled airspace from the ranges south of Stoke and Richmond, immediately adjacent to the approach/departure procedures. The airspace design enables intensive paragliding and hang-gliding activity on the ranges to be formally separated from adjacent IFR flights without what would otherwise be a significant ATC workload.

Using the same principle, extensive collaboration between Gliding New Zealand and Airways BAY sector in 2018 revised general aviation areas (GAA) used for intensive gliding in the Waikato. PBN procedures conflicted with pre-existing GAA in several areas, creating an unacceptable ATC workload when the GAA were activated. The revised GAA enabled gliding access to desired airspace over a wide area, while separating glider traffic by design from PBN procedures used by regular public transport flights through Tauranga, Hamilton, Rotorua and Taupo.

[8] (Ministry of Transport, 2012)

4 Quantifying Benefits

4.1 Changing Context

Previous benefits assessments were based on patterns of air traffic and PBN implementation plans from calendar year 2016, scaling results across future years in line with expected growth in aviation.

The disruption resulting from the Covid19 pandemic has created a clear break from previous travel trends, and significantly affected fuel prices and other input costs. In parallel, the aircraft fleet has been evolving, with the change to more efficient aircraft types being accelerated as a result of the pandemic. Thirdly, the 'as-built' PBN navigation system differs in detail, in both design and timing, from initial general intentions.

Factors most affecting the benefits of the NSS programmes include

- Changing aircraft types and route frequency
- Changing cost inputs, especially fuel price
- Actual PBN implementation design and timing
- Future air transport trends

This report establishes a contemporary baseline for estimating benefits, based on known current and historical air traffic, and using the 'as-built' PBN design.

4.1.1 The Evolving Aircraft Fleet and Fuel Efficiency

Since the 2016-2019 period, the aircraft fleet and the frequency of flights on various routes has evolved.

On some routes, more frequent services using turboprop aircraft have replaced less frequent jet services. More efficient new-generation aircraft have replaced older types. This trend may have been accelerated as a result of the Covid19 pandemic, when many aircraft were furloughed and older or less efficient types retired.

Appendix A.3 lists the most frequent arrivals in the 2016 and 2023 sample years by aircraft type and domestic/international route category, and the overall fuel consumption per nautical mile for the domestic and international flights in those years. The following comments are based on the full data set.

For domestic traffic, the proportions of jet and turboprop traffic are similar. There is a significant shift toward light turboprop aircraft (Cessna Caravan, Pilatus PC-12, King Air, Metro, Jetstream). Although less than 2% of total flights, flights operated by business jets have more than doubled.

Aircraft Category	2016	2023
Narrow Body Jet	25%	25%
Turboprop	63%	55%
Light Turboprop	12%	19%
Business Jet	0.6%	1.5%

Table 4 Domestic Arrivals: Changing Aircraft Categories

International operations are increasingly using more fuel efficient new-generation aircraft types. In the year from August 2022, 41.5% of international flights were operated by Boeing 787 Dreamliner, or Airbus A350, A320neo and A321neo aircraft.

Aircraft Type	2016	2023
Boeing 787 Dreamliner	9.7%	17%
Airbus A320neo	-	11%
Airbus A321neo	-	10%
Airbus A350	0.17%	3.5%

Table 5 Share of International Arrivals by Selected Aircraft Types

Fleet fuel efficiency, in the phase of flight where PBN benefits are delivered, has increased[9]. The changed balance between aircraft types results in a net gain in fuel efficiency of about 8.9% overall, and 4.5% in domestic operations. The following table compares the weighted (by flight frequency) total fuel consumption per nautical mile, as estimated for the late stage of cruise, for flights in the 2016 and 2023 sample years.

Average Fuel Burn (kg/nm)	2016	2023	Change
Domestic	3.06 kg/nm	2.92 kg/nm	- 4.5%
International	7.97 kg/nm	7.22 kg/nm	-9.4%
All	3.81 Kg/nm	3.47 kg/nm	-8.9%

Table 6 Fuel Efficiency Improvement in Domestic and International Fleets

The reducing fuel intensity of flight operations also reduces the fuel savings generated by the PBN navigation system, to the same extent.

4.1.1 Changes in Air Traffic Activity Levels and Cost Inputs

Perhaps counter-intuitively, despite apparent growth, IFR movement numbers in New Zealand have traditionally been more or less constant over the long term. Variations from the long term trend during the life of the NSS programmes include a notable increase in traffic at some airports between 2016 and 2019, apparently driven by rising international tourism and the related rise in internal travel, and a specific decline in traffic at Hamilton with the closure of the L3 pilot training facility.

Global and local constraints affected the volume of air traffic and number of travellers during the Covid-19 pandemic. The disruption resulting from the Covid19 pandemic has seen significant changes in travel demand, and in the ability to service that demand as furloughed aircraft are returned to service and crews are recruited to re-establish air transport capability. Cost inputs have also fluctuated beyond normal bounds, as large changes in the demand for oil and disruption in supply chains for both materials and labour affect the balance between demand and supply.

4.1.1.1 Changing Flight Numbers

Domestic air traffic activity has generally closely followed the local restrictions on travel. International movements have slowly recovered as various international travel restrictions eased and demand recovered after initially being cautious.

New Zealand had several periods of restricted movement as part of the public health response to Covid-19[10]. In brief:

- Covid-19 was a novel zoonotic disease for which humans had little immunity. It was easily transmitted (initially by unknown means) and significant death rates occurred in many countries[11].
- New Zealand successfully adopted an elimination strategy[12] and introduced a four-level alert system with related public health interventions, moving between levels in various regions to control disease

[9] The fuel efficiency metrics used in this report are for a representative fuel efficiency (kg fuel per nautical mile) near the end of cruise where savings from PBN occur. Net overall fuel efficiency may or may not have improved, due to the reduced total trip efficiency in very long haul flights which have a weight burden in the early stages of the flight, imposed by carrying the maximum capacity fuel load required for the trip.

[10] Covid restrictions timelines obtained from (New Zealand Government, 2022a, 2022b, 2022c, 2022d; Stats NZ, 2022)

[11] Excess death rates globally are estimated to be between 221 and 428 per 100,000 population. In the USA: between 390 and 422, in the UK: 371-380, Australia 115-142, New Zealand: between 5 and 13 (Edouard Mathieu, 2020).

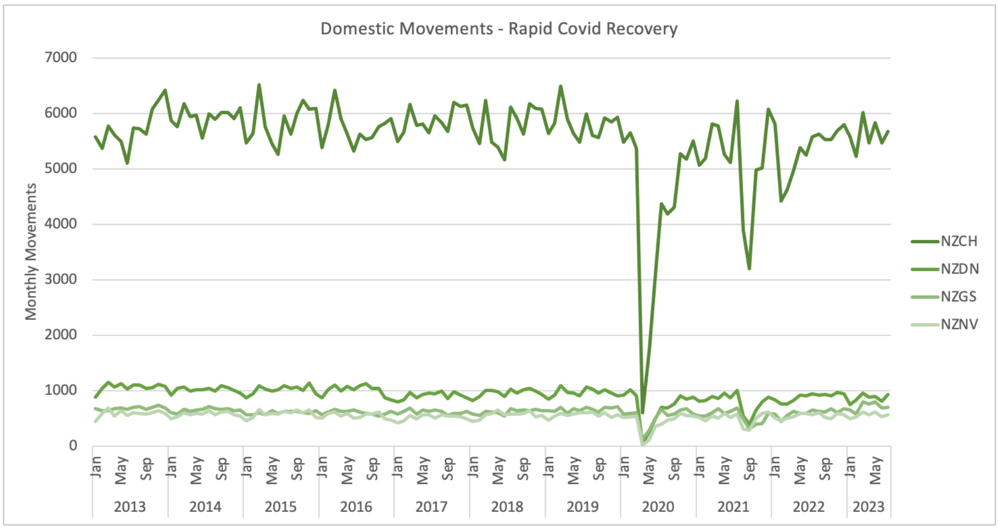
[12] "In 2020, New Zealand adopted an elimination strategy using a wide range of public health interventions in response to the COVID-19 pandemic. This approach successfully eliminated COVID-19, resulted in an 11% reduction in all-cause mortality over a 30-week period in 2020, and enabled the country to ease restrictions by late 2020." (Kung et al., 2023)

outbreaks. Domestic travel ceased during Covid alert level 3 and level 4 conditions. Air travel was possible during alert level 2 and unrestricted during level 1. Nationwide movement restrictions existed from 25 March 2020, reducing in steps to alert level 3 on 27 April, alert level 2 on 13 May.

- New Zealand eliminated the virus domestically during May 2020[13]. Domestic travel became unrestricted from 8 June. During the post-elimination stage, brief regional restrictions were put in place to control imported outbreaks in August/September 2020, February/March, and June 2021. Aircraft load factors were limited by the physical distancing required between passengers until September 2020.
- From the start of 2020 to the end of 2021, the Covid-19 pandemic was highly active internationally. International borders closed to all but returning NZ residents from 19 March 2020. Borders briefly re-opened to vaccinated travellers from Australia in March 2021, but closed again in August 2021 after imported and more contagious strains of the virus took hold in New Zealand.
- An outbreak of the imported and more contagious 'Delta' variant in August 2021 led to level 4 restrictions nationwide from 18 August 2021, reducing from 1 September outside of the Auckland region, and from 22 September in Auckland. Auckland remained at 'Level 3', which restricted air travel on Auckland routes until 16 November.
- New Zealand achieved greater than 95% vaccination coverage of the population in early 2022. That, and remaining public health measures, reduced the possibility of further epidemics to an acceptable extent. Borders were reopened permanently in stages, for eligible travellers from Australia from February 2022 and the rest of the world from 13 March; temporary visa holders, international students and specific others from 12 April, anyone from Australia and visa-waiver travellers from 1 May, and fully reopened from 31 July 2022.

Domestic air traffic activity largely followed travel restrictions. Domestic airport IFR movement levels form three distinct patterns[14]:

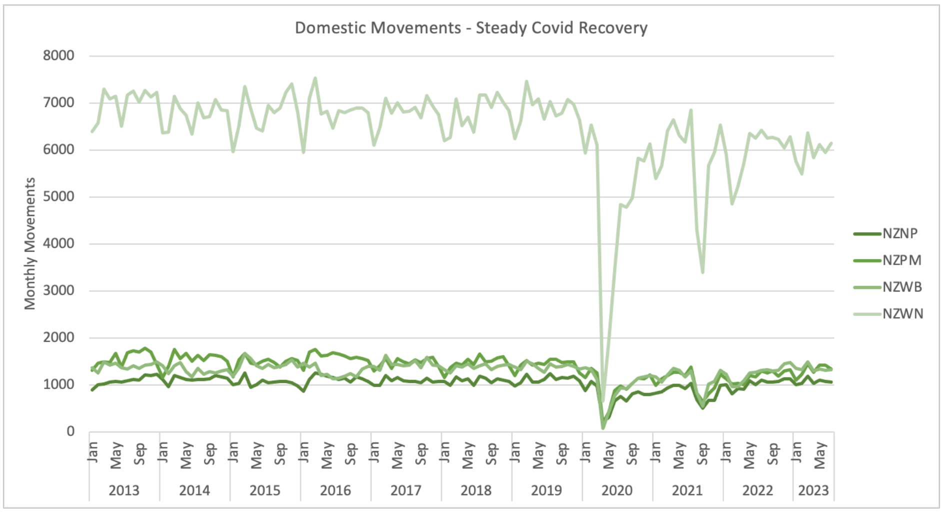
- Airports with stable long term movement numbers and rapid returns to near normal traffic levels.



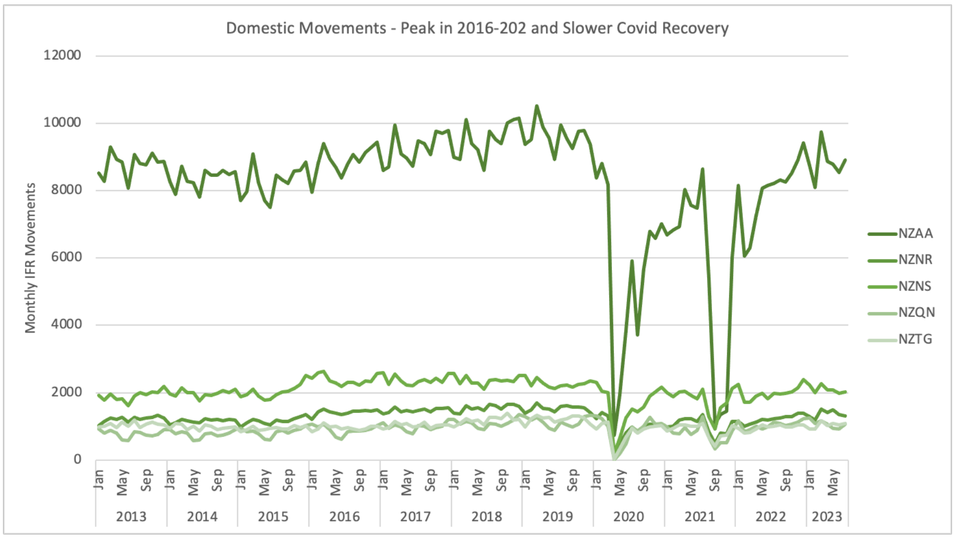
[13] "In early May, the last known Covid-19 case was identified in the community and the person was placed in isolation, which marked the end of identified community spread. On June 8, the government announced a move to Alert Level 1, thereby effectively declaring the pandemic over in New Zealand, 103 days after the first identified case." (Baker et al., 2020)

[14] Data from movement totals published by Airways until June 2022, and flight plan data supplied by Airways for this report.

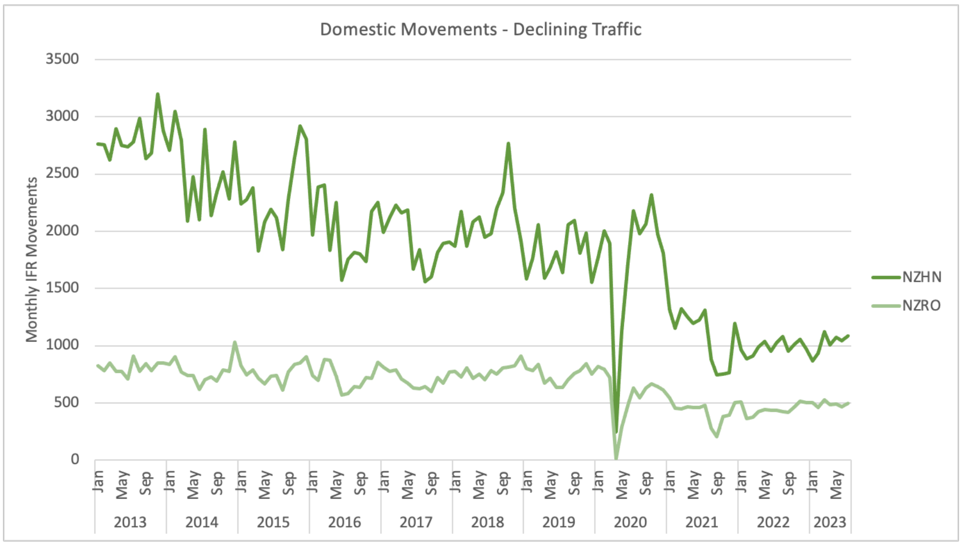
- Airports with stable long term movement numbers and a progressive recovery toward similar levels



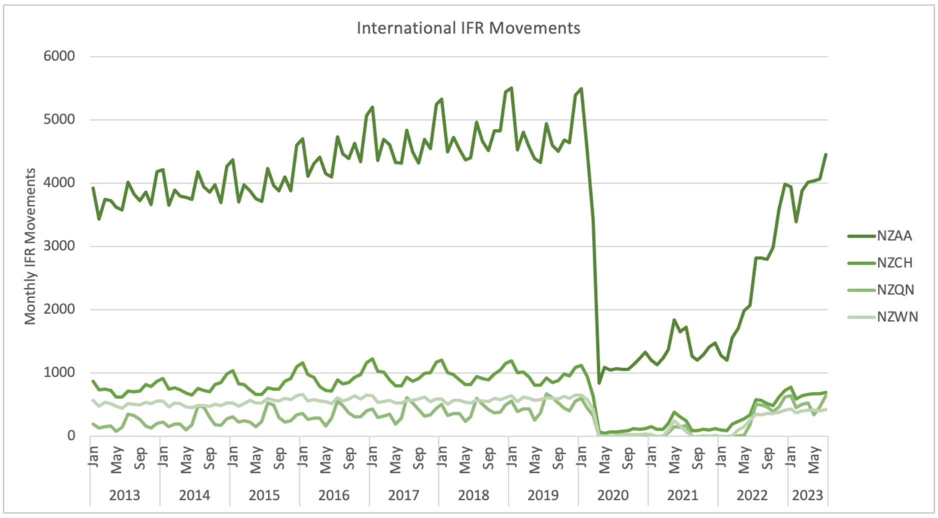
- Airports that experienced higher traffic volumes in the 2016-2019 period recovered more slowly, with part of the resuming domestic movement volume trending in line with recovering international travel.



- Two outliers (Hamilton and Rotorua) have had declining IFR traffic, in the case of Hamilton, largely due to the cessation of the L3 pilot training business in 2020.



International movement volumes rose gradually to approximately 2015 levels, following easing travel restrictions. Freight movements (subsidised through the pandemic to maintain international trading capability) maintained a residual level of international traffic throughout.



4.1.1.2 Changes in Passenger Load Factors

During the Covid-19 public health response period, passenger volumes varied in line with travel restrictions and, apparently, the sensibilities of travellers.

International load factors in the early (2021) border opening were low. At that time, international restrictions in several countries were changing frequently in response to Covid-19 outbreaks[15]. Anecdotally, travellers at that time may have been reluctant to risk becoming ill or stranded during an international trip, and potentially without travel insurance coverage. In contrast, with the permanent restoration of international travel in 2022, once public immunity and any remaining public health measures reduced the likely spread of Covid-19 to acceptable levels, load factors on international flights returned almost immediately to traditional levels[16].

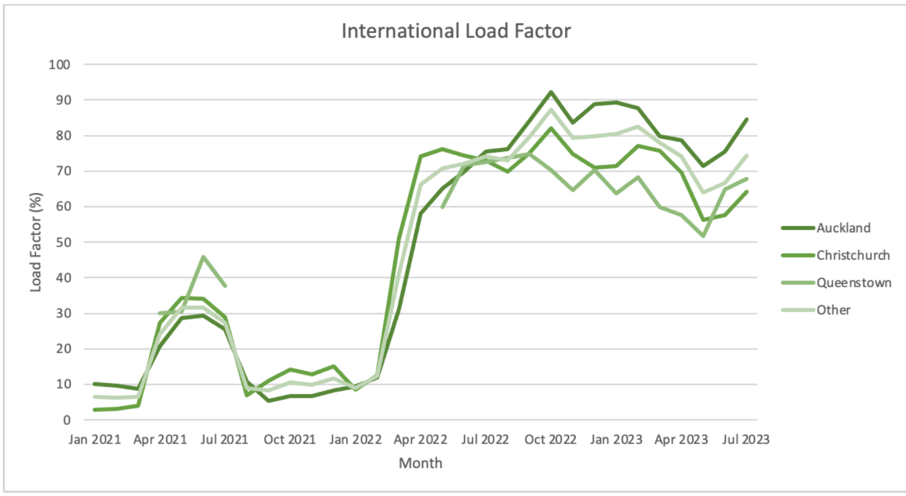


Figure 10 International Load Factors 2021-2022

[15] A travel 'bubble' established between New Zealand and Australia in early 2021 was fragile, with frequent changes to travel and quarantine requirements on both sides of the Tasman. In one instance, increases in Covid-19 community transmissions in Papatoetoe lead Queensland chief health officer to impose quarantine requirements on 24 February 2022 for arrivals from New Zealand, and Air New Zealand to cancel the flight to Brisbane that was boarding at the time .

[16] Passenger information estimated from flight and aircraft data (Airways, FAA, and airline sources), and inferred from monthly passenger numbers published by NZ Airports (Auckland, Christchurch, Queenstown, Nelson).

Load factors on domestic flights in Covid alert level 1 conditions were more or less normal, except during the Covid-19 outbreak in the Auckland region during the second half of 2021. During the period of travel restrictions in the Auckland region, flights to or from Auckland had low load factors, whereas flights on other routes had only moderately reduced load factors. Load factors recovered to normal levels from Q2 2022.

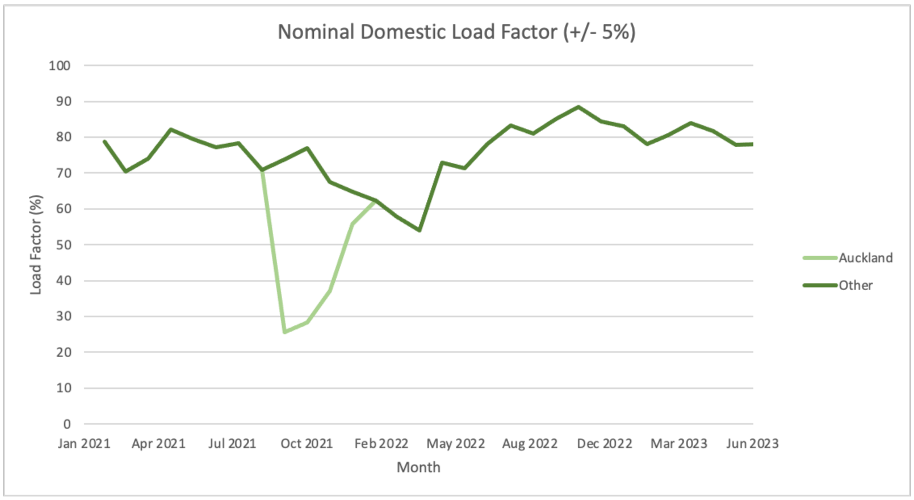


Figure 11 Domestic Load Factors 2021-2022

4.1.1.3 Fuel Price Variability

Contemporaneous changes in demand, supply chain disruption, and many countries banning Russian oil imports in response to the Russian military action in the Ukraine, has resulted in highly variable jet fuel prices through the Covid-19 pandemic years.

The initial large reduction in demand created low but slowly rising prices through 2020. Prices through the post-Covid recovery period have varied rapidly. Although the USD price of jet fuel rose little higher than the price spike during the 'global financial crisis' in 2008, a lower USD/NZD exchange rate created higher spot prices in NZD during 2021-2023.

Given large and often rapid price changes, and large changes in air traffic at times, estimates in this report use jet fuel pricing with monthly granularity. The price applied to fuel savings is the average spot price (in NZD) for the preceding month[17].

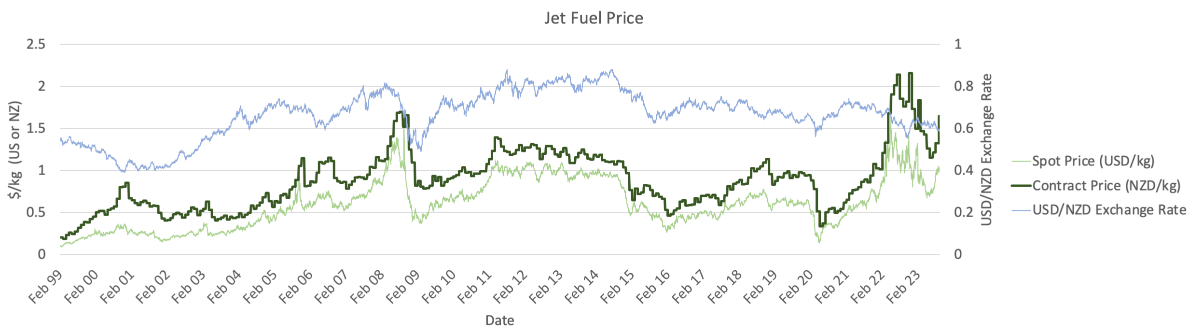


Figure 12 Jet Fuel Pricing 1999-2023

[17] Data sources: Jet Fuel Spot Price:US Energy Information Administration (US East Coast Price), NZD/USD Exchange rate: Reserve Bank of New Zealand

4.2 Current Benefit Estimates

4.2.1 Basis of Estimation

For flights in the sample periods where a complete set of flight data is available, quantified benefits in time, fuel, emissions, and aircraft direct operating cost savings are based on the savings in flight path length resulting from the actual PBN approach taken, compared with the counterfactual: what would occur if the flight had used the applicable conventional navigation system approach.

Benefits are estimated from:

- The actual distance saved based on the PBN design and the route of flight
- Time saving is estimated from the distance saved and the cruise speed of the flight
- Fuel saving is estimated from fuel burn (per nm or per minute) for the aircraft type
- Fuel cost is estimated from fuel savings and the applicable (monthly) fuel price
- Emissions reduction are calculated from fuel savings
- Aircraft direct operating costs are calculated from the time savings, and the estimated average ADOC for the aircraft type.
- Passenger safety benefits for APV are calculated from estimated load factors and the use of PBN procedures at monthly granularity.
- Passenger time savings are calculated from the estimated load factors and flight time savings

To the maximum practicable extent, parameters for fuel burn rates are detailed, per aircraft type, using contemporary estimation methods. Appendix A.4.1 describes the fuel consumption figures used in the analysis. The value of fuel savings is estimated using the relevant monthly fuel price in NZD.

Distance saved per approach are derived from the as-built detailed PBN infrastructure design, as described in section 3.2.2.3 page 12. The full parameter set for the various approaches are tabled in Appendix 5 *Table 21 RNP APCH and RNP AR Flight Path* Reduction*.*

4.2.1.1 Approaches with Vertical Guidance

APV benefits are estimated 'per person', calculating the number of passengers from estimated load factors and the aircraft seating capacity.

Earlier estimates assumed aircraft may make a visual approach in visual conditions at regional airports. The assumption may no longer be correct. There is an increasing trend, for safety and pilot workload reasons, to use instrument flight procedures and autopilot coupled approaches even in visual conditions. This report includes all approaches by flights that (a) plan to make an instrument approach, (b) have PBN VNAV capability, and (c) use a runway equipped with a PBN approach useable by that flight (and no pre-existing ILS), on the basis that NSS has made APV safety benefits available for use by that flight.

4.2.1.2 Savings from Shorter Approaches

Savings from shorter approaches are realised in the cruise phase of flight. In the normal course of events, aircraft flight management systems compute an efficient continuous descent along the selected arrival and approach. The aircraft then commences the descent at the appropriate top-of-descent point along the flight path. For a shorter approach, the aircraft will start descent earlier. The shorter approach effectively moves top-of-descent earlier in the cruise, shortening the cruise phase of flight. Time, fuel, emissions, and aircraft direct operating cost savings are made at the rates occurring at the end of cruise, in proportion to the cruise time saved by the shorter approach.

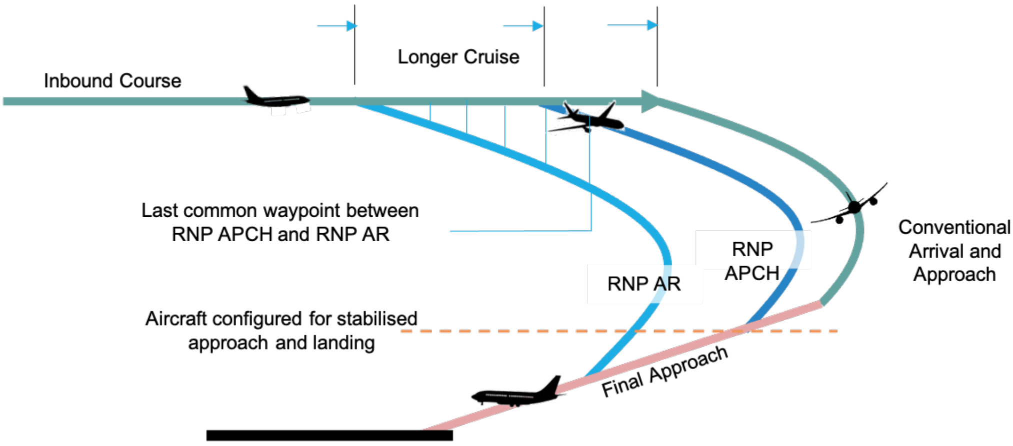


Figure 13 Cruise Duration Changes for Shorter Approach Paths

This estimation method is likely to be conservative, as it disregards additional benefits from continuous descent operations (CDO). The counterfactual – using a conventional navigation approach – often involves level flight segments, descending to and then flying the minimum altitude on each segment of the procedure. In contrast, PBN approaches are usually flown with continuous descent. Estimating the counterfactual would be somewhat speculative, as the outcome is highly dependent on the descent methods used by pilots. Consequently, CDO benefits are noted (and may be substantial) but are not included in the quantified benefits.

4.2.1.3 Impact of Air Traffic Congestion and Operating Practices

PBN benefits are less available in the presence of air traffic congestion. To fully realise these cruise savings, ATC must be able to assign the approach path to the aircraft sufficiently before top of descent for the aircraft to fly undisturbed on the planned approach. In the presence of air traffic congestion, abandoning the initially allocated approach may become an optimum course of action.

ATC constantly balance competing interests - between flight efficiency for individual aircraft, and the optimum overall efficiency for traffic in the terminal area when flights conflict. There is an absolute requirement for safe separation between flights using the runway. Approaching flights will be re-assigned to alternative approaches, or vectored under surveillance control, when aircraft separation could be compromised by allowing then to continue undisturbed on the IFP or when overall flight efficiency in the terminal area would be improved by intervening. In the presence of increased air traffic density, ATC instructions aim to maximise flight efficiency, minimising the overall flight time for all aircraft by maximising runway throughput.

To optimise the overall outcome, ATC may further shorten the flight path with a more direct clearance, or lengthen it to preserve spacing between aircraft using the runway.

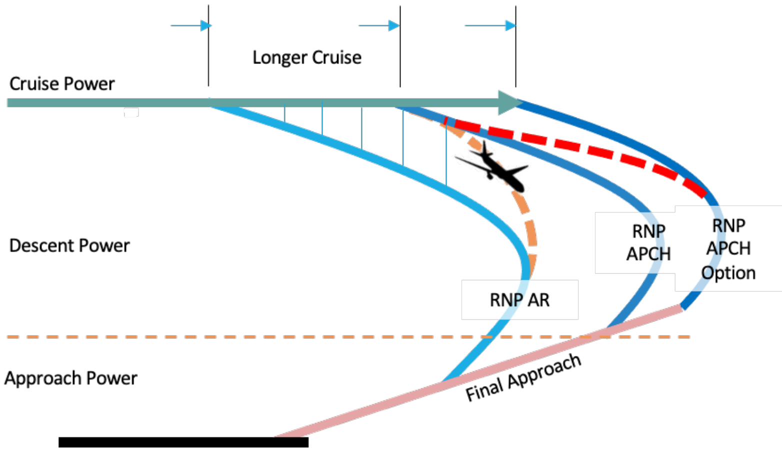


Figure 14 Approach Re-assigned After Top-of-Descent

- Where an approach is shortened, the flight time will reduce. The benefit of the PBN approach is not lost – the aircraft will have commenced descent at the appropriate place, however the additional flight time reduction is attributable to ATC action and not to the NSS. The PBN benefits occur in the cruise at cruise power settings. Further flight path shortening generally occurs during the descent at descent (minimum) power settings[18].

- Where an approach is lengthened, the aircraft will need to use power to achieve the appropriate descent path for a longer approach. The benefits of the PBN approach are not realised, and the aircraft will incur additional flight time and fuel burn[19]. The associated costs are the result of air traffic congestion created by multiple aircraft attempting to operate at much the same time and is not attributable to NSS, nor to ATC. The additional costs for an individual flight may be offset to an extent by overall savings resulting from ATC optimising runway throughput.

4.2.1.1 Aircraft Direct Operating Costs

Apart from fuel savings, systematic reduction in flight time also reduces aircraft direct operating costs (ADOC). For regular operators, systematic reduction in flight time reduces the average block hours on affected routes. Over time, the reduction in block hours can be expected to reduce those non-fuel variable costs which are affected by flight time: crew (technical and cabin crew), maintenance and insurance costs.

ADOC savings are estimated using a nominal average cost per block-hour, for aircraft in generally similar weight, engine number and type groupings. Business Jet types are estimated separately, as the block-hour costs may be greater for less frequently used aircraft. The estimation method and range of ADOC values are described in Appendix 4.5.

4.2.1.2 Other Operational Factors

Air New Zealand ATR72 operations with qualified crew were approved to use RNP AR procedures nationwide from 18 December 2020. RNP AR capability depends on crew qualification as well as aircraft equipment. All crews flying through Queenstown are qualified to use RNP AR. The company is continuing to train the remaining fleet pilots and intends to have all ATR72 flight crew qualified by the start of 2025.

Consistent with reporting benefits once implementation is complete, RNP AR benefits for ATR72 flights are included, at any airport where the aircraft use RNP AR approaches, for flights to or from Queenstown from 18 December 2020.

4.2.2 Quantified Benefits to Date

Table 7 shows the estimated quantified benefits, from the start of the benefit assessment period (January 2015) to July 2023[20].

- Benefits in the period 2021 through July 2023 are estimated from individual flight details, including the approach used.
- Benefits in 2015-2016 are estimated from original flight details and assume the same pattern of use of PBN approaches for the route (origin airport to destination runway) as in 2021-2023 for each flight.
- Benefits for the period 2017-2020 are based on the results for the 2015-2016 period, scaled in accordance with international and domestic traffic volume, assuming a similar balance of aircraft and routes flown.
- Benefits are attributed to NSS from the final implementation date at each destination airport.

---

[18] Reducing flight distance in this segment of the arrival delivers smaller fuel savings than in cruise. The reduction occurs in a phase of flight with the lowest power settings. The result is not as efficient as selecting the shorter approach before top of descent. The aircraft will have already consumed the fuel required for the longer cruise, and will have excess energy for the shorter approach. The shorter approach may be easily navigable, but the aircraft will need to waste the excess energy, including using air brakes if necessary.

[19] For aircraft re-assigned to a longer arrival after top of descent, including when vectored under surveillance control, additional flight miles are incurred at altitudes below cruise, where fuel intensity of flight is greater than at cruise due to a reduced ground speed. Consequently, the additional miles incur a greater cost than they would if executed in the cruise phase of flight. When assigned to a longer IFP after top of descent, the cost of the approach is greater than would be the case if the re-assignment occurred before top of descent.

[20] Figures are shown with 2 or 3 significant figures due to the limited precision of underlying data and therefore may not add to the totals shown.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Flight Distance Saved (nm)	181,000	282,000	311,000	317,000	330,000	219,000	255,000	290,000	188,000	2,370,000
Flight Time Saved (hours)	496	771	869	887	933	632	756	841	532	6,720
Fuel Saved (Tonnes)	757	1,180	1,280	1,300	1,340	853	959	1,100	727	9,480
CO2 Saved (Tonnes)	2390	3730	4040	4100	4230	2700	3030	3460	2300	30,000
Passenger Time Saved (hours)	54,000	85,000	91,000	95,000	97,000	49,000	60,000	74,000	50,000	660,000
Passenger APV	940,000	1,200,000	1,800,000	2,200,000	2,600,000	1,500,000	1,900,000	2,500,000	1,700,000	16,000,000
Fuel Saved (NZD 2023)	822,000	992,000	1,300,000	1,780,000	1,740,000	702,000	990,000	2,240,000	1,080,000	11,600,000
ADOC (NZD 2023)	1,440,000	2,260,000	2,550,000	2,690,000	2,820,000	1,740,000	2,150,000	2,460,000	1,420,000	19,500,000
Value of Passenger Time (NZD 2023)	1,200,000	1,900,000	2,000,000	2,100,000	2,200,000	1,100,000	1,300,000	1,600,000	1,100,000	15,000,000

Table 7 Quantified PBN Benefits to July 2023

Note that 2023 is a part year to the end of July. Financial figures are inflated by the consumer price index[21] from original prices to give results in 2023 NZD. Totals are the simple sum and do not include the time value of money.

Differences from earlier estimates include

- More accurate distance saving based on the actual PBN design
- Actual flight details (rather than extrapolated/estimated totals) for flights from January 2021 on.
- Additional saved distance for Auckland RNP APCH ‘Y’ at night or in IMC
- RNP AR benefits attributed only for aircraft with RNP AR capability
- More fine grained ADOC for various aircraft types
- Higher fidelity fuel burn estimates for Jets
- APV benefits attributed for all flights with VNAV capability that planned IFR approaches to runways with PBN approach procedures
- Updated value of passenger time

4.3 Future Benefits

The PBN infrastructure delivers a permanent marginal gain for IFR operations. The flight efficiency gains are more available at lower air traffic densities and fade due to the need for congestion management once air traffic density reaches about 50% of the airspace capacity. The absolute quantity of future benefits will depend on any changes in traffic volume, the evolving characteristics of aircraft, and changes in input costs.

4.3.1 Aviation Activity Levels

Air traffic volumes in mid 2023 had largely returned to traditional levels. Except for Hamilton, Rotorua, and to some extent Wellington, total domestic and International traffic volumes are close to the long term average levels seen in 2015. International travel continues to rise. Australian visitor numbers have largely returned to pre-Covid levels, and more than fully recovered in Queenstown. Inbound tourism from China is over 50% of pre-covid levels[22].

The industry generally expects a full recovery over the next two years, with ongoing growth beyond that. Boeing’s long term commercial market outlook (2023-2042) states “Despite constraints caused by labor shortages, supply chain issues, and operational restrictions at airports, passenger traffic is set to return to 2019 levels over the course of the next 12-18 months”[23]. Over the longer term, Boeing anticipates GDP growth in the Oceania region of 2.3%, and annual air traffic (passenger) growth of 5.3% on average through to 2042.

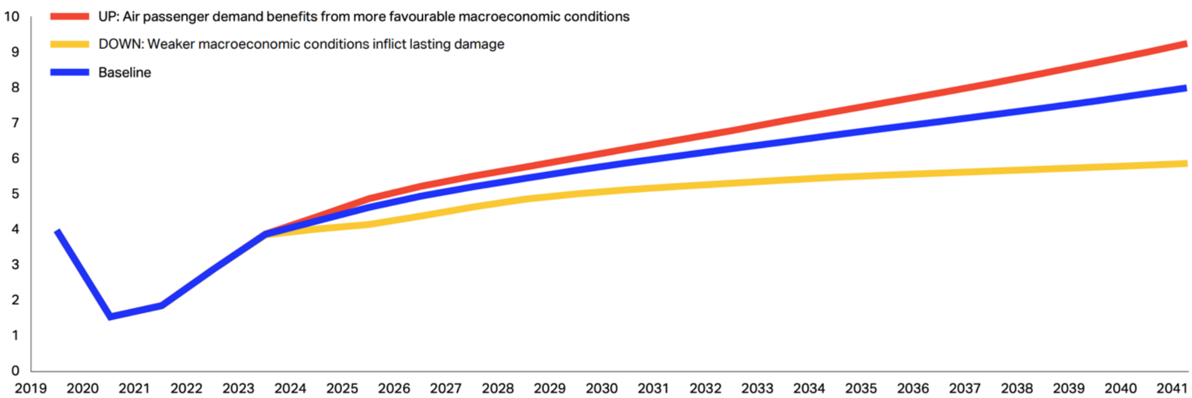
In the near term, supply and demand constraints may restrain growth in domestic travel. Early maintenance inspections on engines fitted to A320neo and A321neo aircraft during 2024[24] may restrict flight schedules[25]. Weaker domestic consumption is anticipated in 2024 and 2025 with private consumption growth at low levels,

[21] (Stats NZ, 2023b)
[22] (The Treasury, 2023. p.12)
[23] (Boeing, 2023)
[24] FAA proposes early and more frequent maintenance inspections and parts replacements on PW1100G engines in a notice of proposed rulemaking issued on 12 December 2023. (Federal Aviation Administration, 2023)
[25] Air New Zealand faces major schedule changes in 2024. (Business Desk, 2023)

and a slight fall in real GDP per capita. Economic and private consumption growth is forecast to resume at modest levels (closely matching Boeing estimates) long term from 2026 [26].

Political, economic, and environmental headwinds exist. IATA's Global Outlook for Air Transport[27] notes a range of well-known geopolitical and environmental factors that are less supportive of air transport including potentially reduced economic growth with the increase in autocracies, increasing violent state-based conflicts, more inward-looking economic policies and fragmentation of trade and investment, shrinking working-age populations, and the impact of climate change. Climate change may affect air traffic levels on two fronts: increasing environmental chaos disrupting air transport at a tactical level and increasing awareness and public sensitivity affecting travel demand. High global debt-to-GDP ratios and total government debt, and higher nominal interest rates long term point to structurally higher global inflation than in the period since 1990 and are expected to dampen economic growth in most global areas, reducing cross-border activity. IATA make an impassioned argument that abundant, sustainable and universally available cheap energy would be transformational, and that the energy transition should be pursued with single-minded focus by all[28]. IATA's conclusion is that air traffic growth may be below previous long term trends and, realistically, that there is a range of uncertainty around the levels of future aviation activity. Nonetheless, provided that the world retains faith in the US economy, IATA expect air transport to grow.

Chart 14: Global air passenger journeys, billion



Sources: IATA Sustainability and Economics, Tourism Economics (September 2023 release)

4.3.2 Evolving Aircraft Fleet Characteristics

Changes in the aircraft fleet are likely to affect the quantity and nature of PBN benefits within the economic life of the NSS programmes (to 2033).

From 2025, ATR72 flights will generally be able to use RNP AR approaches, delivering additional flight time savings at Christchurch, Wellington, Palmerston North and Auckland.

It is also realistic to suppose that more fuel efficient larger aircraft, and partly or fully electric smaller aircraft will start operating prior to 2033.

Proposed (and aspirational) Air New Zealand initiatives[29] aimed at fleet renewal and reducing the carbon intensity of aviation include:

- Continuing upgrades of the domestic and international fleets with A320neo and A32neo aircraft
- Phasing out the Boeing 777-300ER fleet toward the end of the decade to be replaced with Boeing 787-10 Dreamliners powered by GEnx engines.
- Increased use of 'Sustainable Aviation Fuels' (SAF), with a goal to use 10% SAF by 2030.

---

[26] (The Treasury, 2023, Economic Indicators p148)
[27] (International Air Transport Association, 2023)
[28] (International Air Transport Association, 2023, p9)
[29] Information about Air New Zealand initiatives is sourced from the company's Flight NZ0™ sustainability programme, described at https://flightnz0.airnewzealand.co.nz/

- Working to acquire and use next generation aircraft with more sustainable energy sources such as battery-hybrid to replace the Q300 fleet beyond 2030. Suitable replacement aircraft are not yet obvious and the company has partnered with several aircraft developers to work toward creating a viable modest sized aircraft using a more sustainable power supply chain than conventional jet fuel.

Sounds Air also expressed interest in the proposed Heart Aero ES-19 battery electric 19 seat aircraft for the 2026 time frame[30]. The manufacturer has subsequently switched the focus of their developments to a 30 seat hybrid electric aircraft and reports that letters of intent for the ES-19 have been reconfirmed for the larger type[31].

The effect of these changes on NSS benefits include:

- Increased aircraft capacity allows greater passenger numbers for the same number of aircraft movements. Passenger benefits therefore increase more than flight efficiency benefits;
- Increased flight efficiency and additional passenger APV benefits on domestic regional routes due to ATR72 use of significantly shorter RNP AR approaches;
- Reduced jet fuel burn, and therefore proportionately reduced fuel and emissions savings as more efficient aircraft enter service;
- Reduced CO^2 savings as SAF fuel usage increases. Emissions from burning SAF are assumed to be balanced out by biomass carbon uptake during plant growth and therefore counted as zero in Scope 1 (direct emission) greenhouse gas (GHG) reporting[32] used in this report. Reported emissions savings will therefore reduce by the proportion of SAF fuel burned.
- Alternative energy aircraft will continue to realise flight efficiency benefits, however the outcomes may partly become reduced electricity consumption. CO^2 reduction benefits will diminish due to reduced CO^2 emissions from the aircraft. Battery electric aircraft will have zero CO^2 emissions in flight. Future reporting may need to include Scope 3 (supply chain) emissions, and the value of saved source energy.

4.3.3 Future Scenarios

For the period to the end of 2033, a reasonable recovery and 'traditional growth' scenario could assume:

Passenger Growth

- Static or low domestic traffic growth until 2026 in line with forecast domestic consumption
- Steady growth in international passenger numbers in line with recovering international tourism from Asia and local economic growth in New Zealand and Australia. Domestic passenger numbers at some airports correlate with changes international passenger numbers. Estimated domestic passenger numbers for these airports include this component of travel by international visitors.

Rising Movement Numbers

- Recovery of international traffic and return to 2019 traffic levels by the start of 2026. This growth in movement numbers corresponds to the number of flights needed to carry the projected passenger numbers with normal load factors. Except when physical distancing was required to limit the spread of Covid-19, passenger load factors have remained close to traditional levels throughout the Covid-19 pandemic era.
- Growth in domestic movement numbers in line with domestic passenger numbers. Where larger A321neo aircraft are introduced, we assume that they replace A320 types, load factors will remain constant, and the estimated passengers will therefore be carried on proportionately fewer flights.

Benefits change in accordance with PBN availability and aircraft fleet changes

- Benefits of all PBN approaches become fully available from November 2023
- RNP AR Benefits extended to ATR72 operations at Auckland, Palmerston North, Wellington and Christchurch from the start of 2025. Benefits include flight efficiency, and for Christchurch runway 29, APV safety benefits.
- Changes to number of flights and fuel efficiency with the addition of four A320neo/A321neo to the domestic fleet, two by 2024 and two more by 2027.

[30] (Radio New Zealand, 2020)
[31] (Heart Aerospace, 2022)
[32] (World Resources Institute & World Business Council for Sustainable Development, 2004, Chapter 9)

- Fuel efficiency improvements on international flights as B787-10 operations take over from B777-300ER types toward 2030 (assumed progressively over four years starting 2029)
- As an optional scenario: Reduced fuel consumption and emissions on Q300 and possibly changes to Sounds Air flights from 2030 as hybrid or battery-electric aircraft are introduced (assumed progressively over four years starting 2030).
- As an optional scenario: Reduced emissions due to SAF usage increasing to 10% of total later this decade.

4.3.3.1 Risks and Uncertainties

Variations from the default scenario could include:

- Delayed introduction of new aircraft types
- Reduced traffic due to adverse geopolitical, economic, environmental or natural disaster causes.

Future estimates assume that the well-known, high-impact earthquake risks on the Hikurangi Trench and the Main Divide Fault do not occur in the modelled time frame, that the wars in the Middle-East and Eastern Europe do not spread more widely, and that other socio-political risks do not develop to a scale that materially impacts on air travel beyond the characteristics of Boeing/IATA forecasts.

Increasing short term disruptions due to severe weather amplified by accelerating climate heating can be expected. Cyclone and flooding events closed Auckland and Nelson airports for short periods during 2022-2023. The future projection assumes that increasing environmental chaos will increase uncertainty rather than materially changing total traffic volume compared with 2022-2023.

The effects of any future airport at Tarras have not been estimated due to uncertainty about whether the project will proceed, and the likely earliest operational date being 2031 or later[33].

4.3.4 Estimated Future Benefits – Forecast Scenario

4.3.4.1 Evolution in Fuel Savings

Fuel savings vary with increasing PBN benefits and decreasing aircraft fuel consumption. More efficient aircraft generate fewer fuel savings, whilst increasing use of PBN increases the savings attributable to NSS. Figure 15 illustrates a range of effects on domestic fuel savings benefits – the default case without fleet capability changes, and the range of effects resulting from anticipated aircraft upgrades.

- In the default case, fuel savings rise in line with rising fuel consumption.
- The domestic A320 update programme decreases fuel savings in line with reduced consumption.
- The use of RNP AR by the ATR72 fleet creates significant additional savings, as the route shortening, compared with non RNP AR approaches, is substantial[34].
- A range of outcomes may result from introducing hybrid or battery-electric aircraft.

The figure illustrates the cumulative effect resulting from the sequence of changes.

Not all RNP AR capable aircraft fly RNP AR approaches when available. The use of RNP AR approaches depends on the traffic management situation at the time, because aircraft on RNP AR approaches are inflexible for timing. ATC may not offer RNP AR approaches to flights when the outcome could compromise the flow of traffic at the

---

[33] Early indicative timeframes from Christchurch International airport suggested a 6 year time frame for regulatory approval and construction. Validation and planning are ongoing. Future timelines remain tentative, with a first Board decision on whether the project is mature enough to proceed to the approval phase expected ‘sometime in the next 12 months’ (during 2024). (Singleton, 2023)

[34] Note that the actual total fuel consumption is unlikely to align with the savings attributed to NSS. Additional savings over the ‘counterfactual’ (non RNP AR) routes may already be occuring due to direct routing offered by ATC. Actual fuel savings are the sum of savings attributable to NSS, and those attributable to ATC or pilot intervention. Regular use of RNP AR approaches may reduce the benefits of ATC direct clearances, but will increase benefits realised from the NSS intiatives.

point where the RNP AR and other approaches eventually merge. The estimates here assume that ATR72 flights will use RNP AR approaches in the same proportions as jet flights do currently[35].

Airport	% RNP AR approaches by domestic jets
Auckland	41%
Wellington (Rwy 16)	27.9%
Christchurch (Rwy 02)	48.7%
Palmerston North (Rwy 24)	48.7% (assumed)

Table 8 Proportion of Domestic Jet Arrivals using RNP AR Approaches

A variety of outcomes from 2030 onwards are foreseeable depending on the fuel consumption of whatever replaces the Q300 fleet. Hybrid aircraft may be able to operate as battery-electric only on short flights, with onboard jet-fuel (or SAF) powered generators held in reserve to support range extension or for diversions. On longer flights, on board generators may be used to supplement the battery-only range. The two alternatives shown are for a 50% and a 100% reduction in fuel use by the hybrid/electric fleet.

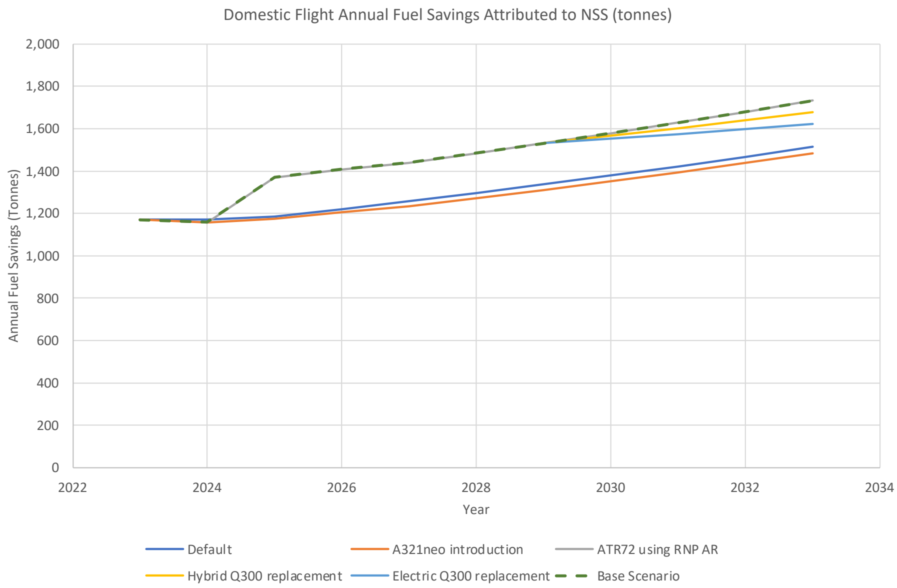


Figure 15 Future Variation of Annual Fuel Savings with Domestic Fleet Capability Changes

4.3.4.2 Net NSS Benefits – Base Scenario

Table 9 shows estimated benefits from August 2023 to the end of the economic life of the NSS programme (2033) for the base future scenario, including all fleet capability changes except for hybrid/electric turboprop replacements, and any use of SAF fuels.

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Total
Flight Distance Saved (nm)	146,000	349,000	437,000	449,000	463,000	478,000	493,000	509,000	526,000	543,000	561,000	4,950,000
Flight Time Saved (hours)	412	987	1,300	1,340	1,380	1,420	1,470	1,520	1,560	1,620	1,670	14,700
Fuel Saved (Tonnes)	576	1,380	1,600	1,640	1,690	1,740	1,800	1,860	1,920	1,980	2,050	18,200
CO2 Saved (Tonnes)	1,820	4,350	5,040	5,190	5,330	5,500	5,680	5,870	6,060	6,260	6,470	57,600
Passenger Time Saved (hours)	38,000	92,000	110,000	110,000	120,000	120,000	130,000	130,000	130,000	140,000	140,000	1,300,000
Passenger APV	1,200,000	2,800,000	2,900,000	3,000,000	3,100,000	3,200,000	3,300,000	3,400,000	3,500,000	3,600,000	3,700,000	34,000,000
Fuel Saved (NZD 2023)	830,000	2,000,000	2,300,000	2,400,000	2,400,000	2,500,000	2,600,000	2,700,000	2,800,000	2,900,000	3,000,000	26,000,000
ADOC Saved (NZD 2023)	925,000	2,210,000	2,820,000	2,900,000	2,980,000	3,080,000	3,180,000	3,280,000	3,390,000	3,500,000	3,610,000	31,900,000
Value of Passenger Time (NZD 2023)	850,000	2,000,000	2,500,000	2,500,000	2,600,000	2,700,000	2,800,000	2,900,000	3,000,000	3,100,000	3,200,000	28,000,000

Table 9 Estimated Future Benefits (Base Scenario)

[35] The proportion of RNP AR approaches at Christchurch and Wellington is runway dependent, as most jet traffic comes from the north at both airports. The figures used for these estimates are those for the runway with the greatest RNP AR useage.

Note that the financial value of fuel savings is only indicative, based on the recent average jet fuel price of NZD 1.45/kg. Fuel price has varied +/- 20% or more in any year, and may vary by 2:1 during a decade. Prices are in constant 2023 NZD and do not include the time value of money.

4.3.4.3 Variations

Air New Zealand's use of 10% SAF fuel by 2030 would reduce CO^2 reduction benefits in proportion to the CO^2 captured by the fuel feed stock. Figure TK illustrates the effect of the Air New Zealand fleet increasing SAF fuel usage by 2% per year from 2026 through 2030. 10% SAF fuel usage would reduce CO^2 savings by 480 tonnes in 2031.

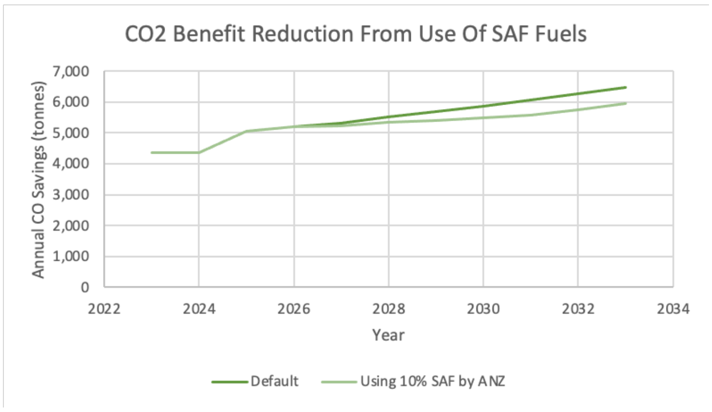


Figure 16 Effect of SAF Fuel Usage Example

The advent of hybrid or battery electric aircraft will reduce fuel consumption and aircraft emissions, with a consequent reduction in the relevant benefits from NSS. In the scenario illustrated in Figure 15, phasing in replacements for the current Q300 fleet over four years starting 2030, benefits would reduce as follows[36].

Relative Fuel Consumption	2030	2031	2032	2033	
50%	-14	-27	-41	-55	Change in Fuel Savings Benefits (Tonnes)
0%	-27	-55	-82	-110	
50%	-43	-87	-130	-173	Change in CO2 Savings Benefits (Tonnes)
0%	-87	-173	-260	-347	

Table 10 Change in Fuel and CO2 Savings For Hybrid/Electric Replacements For Q300 Fleet

PBN will continue to deliver energy efficiency benefits for alternatively powered aircraft. The reduction in fuel savings is matched by savings at the original energy source used to power the aircraft. To present a full account, future benefits assessments would need to quantify these savings, however the likely energy consumption of these aircraft is not known at this time.

4.4 Benefits Summary

Table 11 lists the estimated benefits for the period to date (2015 through July 2023), the moderate 'traditional growth' forecast scenario from August 2023 through 2033, and the overall total.

The use of SAF fuels in line with Air New Zealand's aspirations (10% by 2030, gradually introduced from 2027) would reduce CO^2 savings by about 2,388 tonnes in total (about 2.7% reduction of the NSS total).

The use of hybrid or battery electric aircraft on routes currently served by Q300 turboprops would reduce fuel and emissions savings by up to 274 tonnes (fuel) and 867 tonnes (CO^2) (1% of NSS total).

The most visible risks to realising the future benefits are probably high-impact but highly uncertain geopolitical and environmental risks. Their effects have not been estimated due to the uncertainties.

[36] Note that the reduction in fuel burn savings tabulated here does not represent the savings in fuel burn of the next generation fleet. Fleet fuel burn savings through using hybrid or electric propulsuion will be much greater. These figures are only the component of fuel burn saved by the use of PBN procedures.

Benefit	To Date	Future	Total
Flight Distance Saved (nm)	2,370,000	4,950,000	7,320,000
Flight Time Saved (hours)	6,720	14,700	21,400
Fuel Saved (Tonnes)	9,480	18,200	27,700
CO2 Saved (Tonnes)	30,000	57,600	87,600
Passenger Time Saved (hours)	660,000	1,300,000	2,000,000
Passenger APV	16,000,000	34,000,000	50,000,000
Fuel Saved (NZD 2023)	11,600,000	26,000,000	38,000,000
ADOC Saved (NZD 2023)	19,500,000	31,900,000	51,400,000
Value of Passenger Time (NZD 2023)	15,000,000	28,000,000	43,000,000

Table 11 Estimated Quantifiable NSS Benefits 2015 to 2033

4.5 Perspective

The purpose of this assessment is to estimate to what extent the New Southern Sky benefits are being realised as a result of the NSS investment. The PBN implementation has improved safety, airport accessibility, and airspace capacity, has saved passenger time, has reduced aircraft fuel burn and operating costs, and reduced CO^2 emissions.

Although the fuel and environmental savings are significant, they do not mean that total aviation emissions have reduced. PBN helps reduce the energy intensity of aviation but the gain is proportional and marginal, and easily surpassed by the effect of changing activity levels in aviation. For perspective: in the year from July 2022 to June 2023, the 303,296 jet fuel powered flights that landed in New Zealand flew 442,099 hours, burning an estimated 953,000 tonnes of jet fuel and producing 3,013,000 tonnes of CO^2. PBN Benefits included saving 1,415 tonnes of fuel (0.13%). The figures are dominated by the long cruise of international flights. Domestic flights flew 266,555 hours, burning an estimated 254,000 tonnes of fuel[37] to create 803,000 tonnes of CO^2. Domestic PBN benefits saved 1,280 tonnes of fuel (0.53%).

The air transport industry body Air Transport Action Group (ATAG) have posited various pathways to decarbonise aviation in their 'Vision 2050' report[38]. All of the future scenarios call for operations and infrastructure based improvements to deliver emissions reduction benefits between 9% and 10%, with most improvements made early in the timeline. For domestic operations, the fuel and emissions benefits of PBN, conservatively, deliver at least 5.3% of that goal.

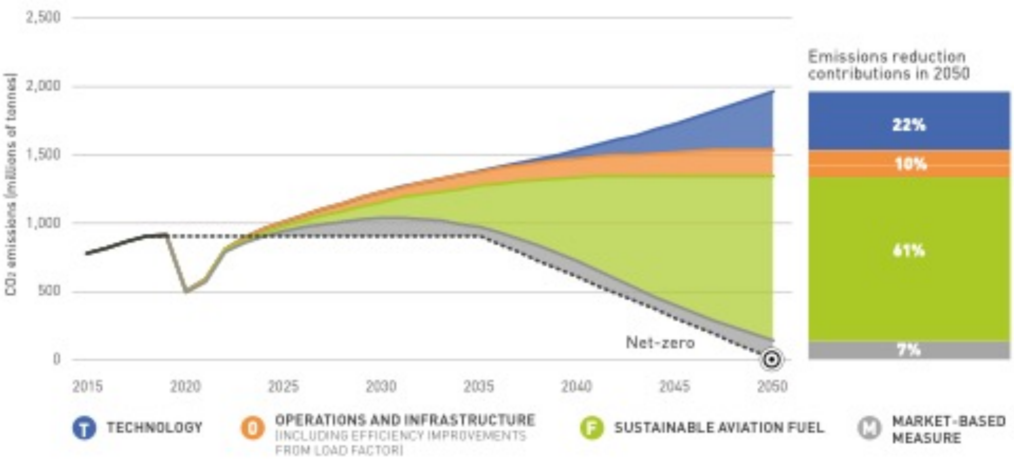


Figure 17 ATAG Net-Zero Scenario 1: Pushing Technology and Operations
Source: 'Waypoint 2050', Air Transport Action Group

[37] Fuel consumption and emissions estimates appear to be close to reality. Air New Zealand report a 'Greenhouse Gas Inventory' annually on the July-June financial year(Air New Zealand Group, 2023). Emissions estimated in this NSS report for the portion of domestic flights operated by Air New Zealand agree with Air New Zealands reported total (691,444 tonnes).
[38] (Air Transport Action Group (ATAG), 2021)

Appendix A Quantified Benefits Modelling

A.1 Aircraft Capability

A.1.1 PBN Technical Standards

ICAO specifies a range of performance standards for PBN procedures.

The two basic categories of PBN navigation techniques are “Area Navigation” (RNAV) and “Required Navigation Performance” (RNP).

- RNAV is a method of navigating a chosen course using any approved combination of (a) a network of ground based navigation aids, (b) GNSS or (c) internal aircraft capability (such as an IRU). In New Zealand, approved navigation sources are GNSS (specifically, GPS), or on some air routes dual ground based distance measuring equipment (DME) combined with IRU.
- RNP adds on-board performance monitoring and alerting. RNP provides performance assurance and integrity, making RNP a requirement where real time quality assurance of the operation’s overall navigation performance is critical to flight safety.

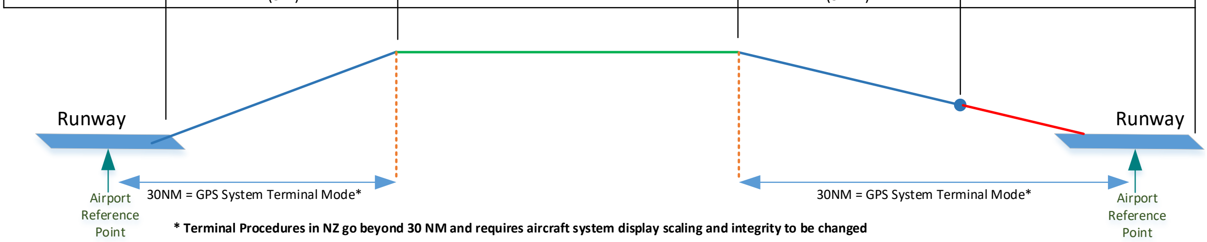
Both RNAV and RNP are qualified by an accuracy level. The nomenclature follows RNAV or RNP with a number indicating the statistical accuracy of navigation, in nautical miles. Typically, the required performance specifies that the total system position error must be within this distance for at least 95% of the total flight time.

A refinement of RNP, required navigation performance approach (RNP APCH) is used for approach procedures. RNP APCH performance has increasing position accuracy at the final stage of the approach.

RNP AR approaches are an alternative, and higher precision standard for approach procedures. Navigation accuracy levels can significantly tighter, allowing approaches to be designed for safe operations in close quarters with terrain and obstacles, and to lower minimum heights.

The New Zealand PBN infrastructure uses selected ICAO standards for various aspects of the navigation system. Pictorially, the PBN specifications implemented in New Zealand, across the phases of flight are:

	Flight Phase			
	Terminal Departure	Enroute	Terminal Arrival	Approach
PBN Specification	RNAV 1 RNP 1 (Standard Instrument Departure) (SID)	RNAV 2 RNP 2 (future deployment)	RNAV 1 RNP 1 (Standard Instrument Arrival) (STAR)	RNP APCH + Missed Approach



Source: Advisory Circular AC91-21, NZ CAA

Figure 18 NZ PBN Specifications by Phase of Flight

A.1.2 Aircraft Equipage

In respect of benefit realisation, aircraft operators participate in PBN benefits to the extent that their aircraft and crews have the required capability for the relevant phases of flight. A variety of capability levels exist across the aircraft fleet operating in New Zealand.

Differences in aircraft capability fall into four broad categories:

- Having no PBN capability at all. Non-equipped aircraft continue to use the conventional navigation infrastructure and receive no PBN benefits.
- Having approach (RNP APCH) capability. Aircraft with approach capability obtain benefits of IFR access to aerodromes that lack conventional navigation means, and the benefits of shorter approaches where the approach design allows
- Having vertical navigation (VNAV) capability on approach. Aircraft capable of VNAV obtain the safety benefits of approaches with vertical guidance (APV).
- Having RNP AR capability. Flights capable of RNP AR can obtain the benefits of (even) shorter approaches; and lower minima, with reduced risk of diversion; and more reliable access to Queenstown.

The following table lists the capabilities of aircraft making at least several IFR approaches in New Zealand in the sample data from 2021 through July 2023. Many aircraft operate in multiple route and operation categories. The table includes each aircraft in the category in which it is most frequently operated in New Zealand.

Nearly all larger air transport aircraft have PBN with APCH and APV capability.

All PBN equipped helicopters have APCH capability.

About 90% of IFR general aviation (GA) aircraft have PBN enroute and SID/STAR capability. About half of these have APCH capability but few have APV.

Aircraft Category				Number of Aircraft	Number of Arrivals	Navigation Method		Capability		
Nationality	Route	Operation	Aircraft Class			Conventional	PBN	RNP APCH	APV	RNP AR
NZ Registered	International	Air Transport	Heavy Jet	21	23360		21	21	21	21
			Narrow Body Jet	9	12400		9	9	9	6
	Domestic	Air Transport	Turboprop	63	270027	3	60	60	52	29
			Narrow Body Jet	45	100840		45	45	39	32
			Light Turboprop	25	52461		25	20	5	
			Light Aircraft	18	3741	6	12	5		
			Helicopter	5	2482		5	5	4	
			Light Business Jet	3	2026		3	3	1	
			Business Jet	3	1937		3	3	3	
		General Aviation	Light Aircraft	145	23844	12	133	79	5	
			Light Turboprop	18	15164	1	17	9	4	
			Helicopter	9	1656	2	7	7	1	
			Light Business Jet	3	822		3	3	1	
			Business Jet	4	679		4	3	2	
Foreign	International	Air Transport	Heavy Jet	588	28346		588	585	571	283
			Narrow Body Jet	79	19396		79	78	74	60
			Business Jet	22	286		22	21	15	
		General Aviation	Business Jet	23	445		23	20	18	
	Domestic	Air Transport	Narrow Body Jet	40	26709		40	38	36	35
		General Aviation	Business Jet	49	2273		49	46	41	3
			Light Business Jet	4	328		4	4		
			Light Aircraft	5	281		5	4		
			Light Turboprop	7	125	2	5	5	4	

Figure 19 Aircraft Fleet Reported PBN Capabilities

A.2 Airports with PBN approaches

The table below lists the current state of PBN implementation at NZ aerodromes (as at the end of November 2023). Bullets indicate the presence of IFR navigation procedures to at least one runway, or to a heliport, and separately identify:

- Approaches using conventional navigation systems (VOR/DME/NDB)
- PBN standard arrival procedures (STARs) and PBN approach procedures
- RNP (AR) approaches
- Medical Facilities

Aerodrome Name	AD Type	Conventional Navigation Approach Procedure	PBN Standard Arrival Procedure (STAR)	PBN Approach Procedure	RNP (AR)	PBN to Medical Facility	IFR Arrivals 2021-July 2023
WAITIKI							
MANGONUI	Heliport						12
KAITAIA		○	●	●			1941
KAITAIA HOSPITAL	Heliport		●	●		✚	162
OTEHEI BAY	Heliport						
KERIKERI/BAY OF ISLANDS		○	●	●			3800
PAIHIA WATERFRONT	Heliport						
PAIHIA	Heliport		●	●			4
BAY OF ISLANDS HOSPITAL	Heliport			●		✚	36
RAWENE HOSPITAL	Heliport		●	●		✚	31
HELENA BAY	Heliport		●	●			2
KAIKOHE							
KENSINGTON PARK	Heliport						7
WHANGAREI HOSPITAL	Heliport						636
WHANGAREI		○		●			4426
DARGAVILLE HOSPITAL	Heliport			●		✚	13
DARGAVILLE							
RUAWAI							
OKIWI STATION			●	●			12
MOTU KAIKOURA ISLAND							
GREAT BARRIER			●	●			7373
WELLSFORD	Heliport			●			30
SPRINGHILL							
OMAHA FLATS			●	●			3
WARKWORTH	Heliport		●	●			3
KAIPARA FLATS							
PARAKAI			●	●			2
NORTH SHORE			●	●			879
ROSEDALE ROAD	Heliport						
ROSEDALE	Heliport						
NORTH SHORE HOSPITAL	Heliport						2
WHENUAPAI				●			
COROMANDEL				●			9
WAIHEKE							6
KAUAROA BAY	Heliport						
WHITIANGA				●			751
AUCKLAND HARBOUR							
MECHANICS BAY	Heliport						48
AUCKLAND HOSPITAL	Heliport			●		✚	589
PIKES POINT	Heliport						
AUCKLAND		○	●	●	◇		147954

Aerodrome Name	AD Type	Conventional Navigation Approach Procedure	PBN Standard Arrival Procedure (STAR)	PBN Approach Procedure	RNP (AR)	PBN to Medical Facility	IFR Arrivals 2021-July 2023
PAUANUI BEACH			●	●			20
ARDMORE			●	●			2502
DRURY							
THAMES HOSPITAL	Heliport			●		✚	25
THAMES				●			6
WHANGAMATA	Heliport		●	●			11
MERCER							4
PUKEKOHE							15
WAIHI BEACH							1
TE ARAROA							
TAURANGA		○	●	●			14519
TAURANGA HOSPITAL	Heliport						74
MATAMATA							1
TE KOWHAI							10
RAGLAN							1
WAIKATO HOSPITAL	Heliport		●	●		✚	410
HAMILTON		○	●	●			15592
RUATORIA							1
WHAKATANE		○	●	●			2075
WHAKATANE HOSPITAL	Heliport						48
OPOTIKI							1
TE PUIA SPRINGS HOSPITAL	Heliport						
ROTORUA		○	●	●	◇		6588
ROTORUA LAKES							
ROTORUA LAKEFRONT	Heliport						
ROTORUA HOSPITAL	Heliport						86
WHAREPAPA SOUTH							
TAHAROA IRONSANDS	Heliport						
TOKOROA HOSPITAL	Heliport			●		✚	12
TOKOROA				●			74
TE KUITI							1
TE KUITI HOSPITAL	Heliport		●	●		✚	12
GALATEA							
GISBORNE HOSPITAL	Heliport						15
HUKA FALLS	Heliport						
GISBORNE		○	●	●			9382
CENTENNIAL PARK							
TAUPO HOSPITAL	Heliport						44
TAUPO WATER							
TAUPO		○	●	●			3382
TAUMARUNUI							
RANGITAIKI							
TAUMARUNUI HOSPITAL	Heliport		●	●		✚	41
TURANGI							3
NEW PLYMOUTH		○	●	●			14574
WAIROA		○	●	●			1468
WAIROA HOSPITAL	Heliport						
TARANAKI BASE HOSPITAL	Heliport						29
NORFOLK							
STRATFORD							
NAPIER		○	●	●			18137
HAWERA				●			501
MAUI A	Heliport						
HASTINGS HOSPITAL	Heliport						4
MAUI B	Heliport						
HASTINGS				●			576
TAIHAPE							
KOWHAI							
KUPE	Heliport			●			1
FLAT HILLS							
WHANGANUI HOSPITAL	Heliport						1
WHANGANUI		○	●	●			5889

Aerodrome Name	AD Type	Conventional Navigation Approach Procedure	PBN Standard Arrival Procedure (STAR)	PBN Approach Procedure	RNP (AR)	PBN to Medical Facility	IFR Arrivals 2021-July 2023
RAROA	Heliport		●	●			
WAIPUKURAU							14
OHAKEA		○	●	●			
DANNEVIRKE							3
FEILDING							232
PORANGAHAU							
PALMERSTON NORTH		○	●	●	◇		17866
PALMERSTON NORTH HOSPITAL	Heliport						2
FOXPINE							9
KOPUTAROA							
OTAKI							
TAKAKA			●	●			707
PARAPARAUMU			●	●			3071
WAIRARAPA HOSPITAL	Heliport						
MASTERTON			●	●			931
PAPAWAI							
MOTUEKA							12
KENEPURU HOSPITAL	Heliport						
AVALON	Heliport						
TASMAN	Heliport						
KARAMEA							3
FLAT POINT							
MARLBOROUGH SOUNDS							
QUEENS WHARF	Heliport						
NELSON HOSPITAL	Heliport						
NELSON		○	●	●			29553
WELLINGTON HOSPITAL	Heliport						1
WELLINGTON		○	●	●	◇		93135
EVES VALLEY	Heliport						
PICTON							1132
CLOUDY BAY							1
WOODBOURNE		○	●	●			18623
WAIRAU HOSPITAL	Heliport						
OMAKA							124
WESTPORT		○	●	●			1770
LAKE STATION/NELSON LAKES							
MURCHISON							
MURCHISON HOSPITAL	Heliport						
KAIKOURA BEACHFRONT	Heliport						
KAIKOURA MEDICAL CENTRE	Heliport			●		✚	
KAIKOURA		○					27
GREYMOUTH			●	●			581
HANMER							
LAKE HAUPIRI							
HOKITIKA		○	●	●			1880
LOBURN ABBEY							
RANGIORA							12
FERNSIDE FIELDS							4
MID WAIHO LOOP							
FRANZ JOSEF							
SPRINGFIELD							
FOREST FIELD							
GLACIER COUNTRY	Heliport						
FOX GLACIER							5
FOX	Heliport						
FOX RIVER	Heliport						
WEST MELTON							6
BURWOOD HOSPITAL	Heliport						
CHRISTCHURCH		○	●	●	◇		86472
CHRISTCHURCH HOSPITAL	Heliport			●		✚	108
CHRISTCHURCH HOSPITAL HAGLEY	Heliport						
PUDDING HILL							1
MOUNT COOK							3

Aerodrome Name	AD Type	Conventional Navigation Approach Procedure	PBN Standard Arrival Procedure (STAR)	PBN Approach Procedure	RNP (AR)	PBN to Medical Facility	IFR Arrivals 2021-July 2023
ANAMA							
CHATHAM IS/TUUTA		○		●			950
HAAST							
ASHBURTON MEDICAL CENTRE	Heliport			●		✚	5
ASHBURTON							16
GLENTANNER				●			99
TEKAPO							6
TEKAPO / MACKENZIE	Heliport						
RANGITATA ISLAND							
MAKARORA							1
MAKARORA HELIPORT	Heliport						
PUKAKI							6
TWIZEL MEDICAL CENTRE	Heliport		●	●		✚	3
TIMARU		○	●	●			2734
MARTINS BAY							
TIMARU HOSPITAL	Heliport			●		✚	12
OMARAMA							2
MILFORD SOUND							
WANAKA LAKES HEALTH CENTRE	Heliport		●	●		✚	
WANAKA			●	●			1520
WAIMATE							
GLENORCHY							
OAMARU			●	●			178
CROMWELL							
QUEENSTOWN		○	●	●	◇		18050
CROMWELL RACECOURSE							
OAMARU HOSPITAL	Heliport		●	●		✚	28
RANFURLY MEDICAL CENTRE	Heliport		●	●		✚	
DUNSTAN HOSPITAL	Heliport		●	●		✚	73
ALEXANDRA				●			143
ROXBURGH							
TE ANAU / MANAPOURI			●	●			51
LUMSDEN MEDICAL CENTRE	Heliport		●	●		✚	3
TAIERI			●	●			57
DUNEDIN HOSPITAL	Heliport		●	●		✚	272
DUNEDIN CITY	Heliport						
DUNEDIN		○	●	●			12978
TAPANUI MEDICAL CENTRE	Heliport		●	●		✚	
MANDEVILLE							
CENTRE BUSH							
GORE HOSPITAL	Heliport		●	●		✚	9
GORE							
BALCLUTHA			●	●			3
INVERCARGILL		○	●	●			8148
SOUTHLAND-KEW HOSPITAL	Heliport		●	●		✚	84
OCEAN BEACH	Heliport						
FERN GULLY	Heliport						
RYANS CREEK			●	●			66
OBAN	Heliport		●	●			5
Total		**28**	**63**	**85**	**6**	**24**	566657

Table 12 IFR Arrival Procedures Implemented at New Zealand Airports

Aerodrome data sourced from NZ Aviation Information Publication, September 2023.

A.3 Fleet and Route Frequency Evolution

Fuel, emissions, and ADOC benefits of the PBN programme primarily arise from flight time saved as a result of changes in the approach procedures. Benefits accrue per arrival, according to the flight distance saved. The value of any benefit depends on the specific characteristics of the aircraft: it's speed, fuel flow, direct operating cost, and number of passengers.

Since earlier benefit estimates, the aircraft fleet is more diverse, and more fuel efficient than previously. Many scheduled services now operate with alternative aircraft types from those previously used on the route.

To illustrate the nature of the fleet and flight frequency for each aircraft type, the following tables list the number of arrivals per aircraft type, for the top 92% of movements in the 2016 and 2023 sample years. The benefits analysis uses the full underlying data set.

A.3.1 2016 Fleet Frequency

Route Category	ICAO Type code	Aircraft Type	Aircraft Category	Number of arrivals	% of Arrivals	Cumulative % of Arrivals
Domestic	DH8C	De Havilland Canada Dash 8 (300)	Turboprop	69106	26.2	26.2
Domestic	A320	Airbus A-320	Narrow Body Jet	49413	18.7	44.9
Domestic	AT76	Atr Atr-72-600	Turboprop	26294	10	54.9
Domestic	AT75	Atr Atr-72-500	Turboprop	23897	9.1	64
International	B738	Boeing 737-800	Narrow Body Jet	10900	4.1	68.1
Domestic	C208	Cessna Grand Caravan	Light Turboprop	9907	3.8	71.9
International	A320	Airbus A-320	Narrow Body Jet	9499	3.6	75.5
Domestic	B190	Beech 1900	Turboprop	6278	2.4	77.9
Domestic	PC12	Pilatus Pc-12	Light Turboprop	4447	1.7	79.5
Domestic	C172	Cessna 172	Light Aircraft	3666	1.4	80.9
Domestic	DA42	Diamond Da-42 Twin Star	Light Aircraft	3642	1.4	82.3
International	B772	Boeing 777-200	Wide Body Jet	2906	1.1	83.4
International	B789	Boeing 787-9 Dreamliner	Wide Body Jet	2884	1.1	84.5
Domestic	BE9L	Beech 90 (A90) King Air	Light Turboprop	2711	1	85.5
Domestic	SW4	Fairchild Swearingen Metro	Light Turboprop	2694	1	86.6
Domestic	BE20	Beech 200 Super King Air	Light Turboprop	2685	1	87.6
International	B77W	Boeing 777-300er	Wide Body Jet	2620	1	88.6
Domestic	B734	Boeing 737-400	Narrow Body Jet	1967	0.7	89.3
Domestic	PA31	Piper Navajo Chieftain	Light Aircraft	1742	0.7	90
International	B763	Boeing 767-300	Wide Body Jet	1599	0.6	90.6
Domestic	CVLT	Convair Cv-580	Turboprop	1487	0.6	91.1
Domestic	JS32	Jetstream Bae-3200 Jetstream Super 31	Turboprop	1424	0.5	91.7
International	A388	Airbus A-380-800	Super Heavy Jet	1364	0.5	92.2

Table 13 Fleet Frequency 2016

Note: Percentages are rounded and may not add vertically

For aircraft using jet fuel:

Route and Aircraft Category	Number of Arrivals	% of Arrivals	% of Route Category
⊟ Domestic	**207869**	**84.85%**	**100.00%**
Turboprop	130362	53.21%	62.71%
Narrow Body Jet	51620	21.07%	24.83%
Light Turboprop	24323	9.93%	11.70%
Business Jet	1280	0.52%	0.62%
Wide Body Jet	284	0.12%	0.14%
⊟ International	**37121**	**15.15%**	**100.00%**
Narrow Body Jet	20882	8.52%	56.25%
Wide Body Jet	14442	5.89%	38.91%
Super Heavy Jet	1364	0.56%	3.67%
Business Jet	377	0.15%	1.02%
Turboprop	29	0.01%	0.08%
Light Turboprop	27	0.01%	0.07%
Grand Total	**244990**	**100.00%**	

Table 14 Proportion of Flight Frequency by Aircraft and Route Category 2016

Route Category	Total Cruise Fuel per nm (Tonnes)	Number of Arrivals	Average Fuel per nm (kg)
Domestic	639.9	207869	3.06
International	295.7	37121	7.97
Total	932.6	244990	3.81

Table 15 Fleet Fuel Efficiency 2016

A.3.2 2021-2023 Fleet Frequency

Route Category	ICAO Type Code	Aircraft Type	Aircraft Category	Number of Arrivals	% of Arrivals	Cumulative % of Arrivals
Domestic	AT76	Atr Atr-72-600	Turboprop	55462	21.6	21.6
Domestic	DH8C	De Havilland Canada Dash 8 (300)	Turboprop	53310	20.8	42.4
Domestic	A320	Airbus A-320	Narrow Body Jet	43926	17.1	59.6
Domestic	C208	Cessna Grand Caravan	Light Turboprop	15744	6.1	65.7
Domestic	PC12	Pilatus Pc-12	Light Turboprop	7732	3	68.7
International	B738	Boeing 737-800	Narrow Body Jet	6712	2.6	71.3
International	B789	Boeing 787-9 Dreamliner	Wide Body Jet	5460	2.1	73.5
Domestic	B734	Boeing 737-400	Narrow Body Jet	3523	1.4	74.8
International	A20N	Airbus A-320neo	Narrow Body Jet	3517	1.4	76.2
Domestic	BE20	Beech 200 Super King Air	Light Turboprop	3515	1.4	77.6
Domestic	BE20	Beech 200 Super King Air	Light Turboprop	3433	1.3	78.9
Domestic	A21N	Airbus A-321neo	Narrow Body Jet	3313	1.3	80.2
Domestic	SF34	Saab 340	Turboprop	3265	1.3	81.5
International	A21N	Airbus A-321neo	Narrow Body Jet	3180	1.2	82.7
International	A320	Airbus A-320	Narrow Body Jet	2850	1.1	83.8
International	B77W	Boeing 777-300er	Wide Body Jet	2196	0.9	84.7
Domestic	DA42	Diamond Da-42 Twin Star	Light Aircraft	2145	0.8	85.5
Domestic	SW4	Fairchild Swearingen Metro	Light Turboprop	1915	0.7	86.3
Domestic	C172	Cessna 172	Light Aircraft	1882	0.7	87
International	A332	Airbus A-330-200	Wide Body Jet	1742	0.7	87.7
Domestic	JS32	Jetstream Bae-3200 Jetstream Super 31	Turboprop	1351	0.5	88.2
Domestic	JS32	Jetstream Bae-3200 Jetstream Super 31	Turboprop	1338	0.5	88.7
Domestic	DA40	Diamond Da-40 Diamond Star	Light Aircraft	1328	0.5	89.3
Domestic	BE9L	Beech 90 (A90) King Air	Light Turboprop	1195	0.5	89.7
Domestic	BE9L	Beech 90 (A90) King Air	Light Turboprop	1152	0.4	90.2
International	A359	Airbus A-350-900 Xwb	Wide Body Jet	1097	0.4	90.6
Domestic	A139	Agustawestland Uh-139	Helicopter	1059	0.4	91
Domestic	A20N	Airbus A-320neo	Narrow Body Jet	803	0.3	91.3
Domestic	JS31	British Aerospace Bae-3100 Jetstream 31	Light Turboprop	798	0.3	91.6
Domestic	P68	Partenavia P-68	Light Aircraft	774	0.3	91.9
Domestic	BE30	Beech 300 Super King Air	Light Turboprop	742	0.3	92.2

Table 16 Fleet Frequency 2021-2023

Note:Percentages are rounded

Route and Aircraft Category	Sum of nb_arrivals	% of arrivals	% of Route Category
Domestic	**211869**	**87.21%**	**100.00%**
Turboprop	116147	47.81%	54.82%
Narrow Body Jet	52596	21.65%	24.82%
Light Turboprop	39398	16.22%	18.60%
Business Jet	3113	1.28%	1.47%
Wide Body Jet	615	0.25%	0.29%
International	**31070**	**12.79%**	**100.00%**
Narrow Body Jet	17314	7.13%	55.73%
Wide Body Jet	12619	5.19%	40.61%
Business Jet	674	0.28%	2.17%
Super Heavy Jet	373	0.15%	1.20%
Turboprop	77	0.03%	0.25%
Light Turboprop	13	0.01%	0.04%
Grand Total	**242939**	**100.00%**	

Table 17 Proportion of Flight Frequency by Aircraft and Route Category 2021-2023

Route Category	Total Cruise Fuel per nm (Tonnes)	Number of Arrivals	Average Fuel per nm (kg)
Domestic	618.4	211869	2.92
International	224.4	31070	7.22
Total	848.2	242939	3.47

Table 18 Fleet Fuel Efficiency 2021-2023

A.4 Quantitative Model Parameters

A.4.1 Fuel Consumption

Earlier benefits analyses have been based on a legacy database supplied for the study, which contained approximate fixed estimates of cruise fuel flow rates for the most frequently seen aircraft types. For other types, the analysis used an average of the known types in the same weight and engine category (Mahino Consulting, 2017, p. 35).

In the intervening period, the intensifying interest in the environmental impact of aviation has created a significant body of research work estimating aircraft fuel consumption under various conditions.

For the first time, direct analytic formulae are now available for estimating cruise fuel burn (Poll & Schumann, 2021a, 2021b). The method estimates cruise fuel burn rates for 53 jet aircraft types, including the majority of types used in New Zealand. The estimation method was developed from basic aerodynamics and thermodynamics theory and calibrated against a range of wide-body, narrow-body and business jet types. Error estimates and sensitivity analysis show that "estimates of the fuel burn rate are expected to be in error by no more than 5% in the majority of cases."(Poll & Schumann, 2021a, p.296)

Cruise fuel burn is affected by the aircraft speed, flight level, weight and the air temperature. The estimation method can take speed, flight level and weight into account. It is valid for a general atmosphere, making knowledge of the vertical temperature gradient through the atmosphere unnecessary[39]. For the purpose of this report, we estimate the fuel efficiency at an optimum cruise speed and level.

Actual aircraft weights are not known. Where fuel is saved as a result of using PBN approaches, the savings occur at the end of the cruise phase of flight due to the aircraft reaching top of descent earlier. We assume a representative aircraft weight based on a 27% fuel load (representing end-of-cruise fuel state) and a full payload. For narrow-body jets this is roughly 80% of maximum take-off weight (MTOW), and 70% of MTOW for wide-body jets.

Fuel burn will be somewhat over-stated for aircraft with a lower payload, and under-stated for aircraft operating other than at optimum speed and flight level. These estimation compromises can reasonably be expected to offset each other to some extent, as not all aircraft operate with a full payload or at optimum cruise altitude. This approximation in fuel burn is not expected to be more significant than the approximation in estimated flight distance savings.

For jet aircraft not in the 53 types covered by the analytic method, this report continues with the previous practice of using an average of aircraft with a similar weight, and number of engines.

For turboprop aircraft, nominal cruise fuel flows (in kg/hr) have been collated from a variety of sources including manufacturer's publications and user experience. Cruise fuel flow for turboprop aircraft is highly dependent on altitude and speed, varying by 20% or more depending on the selected cruise mode (long range, intermediate, or high speed cruise). The estimates in this report are therefore approximate. The nominal figures used in this analysis are:

[39] This does not mean that temperature is not taken into account in the estimation method. The method includes the effects of aircraft drag, required thrust, and engine efficiency from first principles using general gas laws in a way that ends up not depending on temperature. In effect, the temperature aspects 'cancel out' in the mathematics, yet the results are valid based on fundamental themo-aerodynamics.

ICAO Type Code	Aircraft Type	Nominal Fuel Flow (kg/hr)
AC90	Gulfstream Aerospace 690 Jetprop Commander 840	261
AT5T	Air Tractor At-502	163
AT75	Atr Atr-72-500	650
AT76	Atr Atr-72-600	650
AT8T	Air Tractor At-802	245
B350	Beechcraft 300 (B300) King Air 350	336
BE20	Beech 200 Super King Air	336
BE30	Beech 300 Super King Air	336
BE9L	Beech 90 (A90) King Air	336
C208	Cessna Grand Caravan	144
C425	Cessna 425 Conquest 1	261
C441	Cessna 441 Conquest	220
CRES	New Zealand Cresco	163
CVLT	Convair Cv-580	907
DH8C	De Havilland Canada Dash 8 (300)	900
DHC6	De Havilland Canada Cc-138 Twin Otter	261
F406	Cessna Caravan 2	261
JS31	British Aerospace Bae-3100 Jetstream 31	313
JS32	Jetstream Bae-3200 Jetstream Super 31	313
MU2	Mitsubishi Mu-2	205
P46T	Piper Malibu Meridian	140
P750	Pacific Aerospace 750xl	163
PAY4	Piper Cheyenne 400	208
PC12	Pilatus Pc-12	204
SF34	Saab 340	435
SW4	Fairchild Swearingen Metro	320

Table 19 Nominal Cruise Fuel Flow for Turboprop Aircraft Types

A.4.2 Fuel Cost

The value of fuel savings in this report are calculated using the default IATA formula pricing method.

The IATA *Aviation Fuel Supply Model Agreement* (IATA, 2023) formula defaults to using an average price based on a published third party index quotation (such as *Platts*) for the preceding period, plus an agreed differential, for fuel supply during the following period. Example text in the model contract suggests monthly pricing. In accordance with that example, we model the cost of fuel at the average price for the previous month.

Although some operators may buy fuel at spot prices, for the purposes of modelling fuel prices, we have assumed that major operators would use contracted formula prices for fuel purchases. Where this assumption is incorrect, for air operators with reasonably constant schedules the difference will simply delay fuel price changes by a month rather than affecting the long run totals.

Fuel prices are based on US Gulf Coast spot prices for jet fuel (US Energy Information Administration, 2023), converted to NZD using the daily NZD exchange rate(Reserve Bank of New Zealand, 2023).

The US EIA values are in units of USD/US Gallon, whereas aircraft consumption is in kg. We convert US gallons to Kg using the IATA nominal conversion rate:

1 Metric Tonne = 331 US gallon

The value of fuel savings is calculated by applying the resulting monthly fuel price in NZD / kg to the estimated monthly fuel savings.

A.4.3 Load Factor and Passenger Numbers

Passenger load factors have been estimated using representative aircraft seating capacity from publicly available airline sources, monthly domestic and international passenger numbers published by Auckland, Christchurch, Nelson and Queenstown airports, the aircraft movement data contained in flight plans and overall IFR monthly movement data provided by Airways.

To estimate load factors at other airports, a single statistically derived monthly figure is used for domestic and international passenger load factors for all flights, with a separate figure for flights to and from Auckland during the extended Covid-19 restrictions in late 2021.

Passenger numbers are computed from aircraft seat numbers and the statistical load factor.

Source data contains some uncertainty. As well, the single-figure creates an approximation which may not completely align with local seasonal factors at any particular airport. The approximated load factor is generally within +/- 3% of reported domestic passenger numbers and +/- 7% of reported international passenger numbers at airports for which good data is available. Passenger related benefits are therefore reported to only 2 significant digits.

A.4.4 The value of Passenger Time

For the value of passenger time, estimates use the average value of travel time for work and non-work travel in the current Waka Kotahi Monetised Benefits and Costs Manual(Waka Kotahi, 2023)

Travel Purpose	Value of Travel Time (NZD 2023)
Work	37.92
Non Work	6.61
Average	22.27

A.4.5 Aircraft Direct Operating Costs

Quantifying variable block hour costs for aircraft is challenging as the data is not only commercially sensitive, but varies widely between operators depending on the utilisation rate of aircraft, route lengths, and the cost structure of the operator's business[40]. The US Department of Transport comprehensively surveys commercial operators in the US, and the reported variable costs per block hour vary by up to an order magnitude between low-utilisation and high-utilisation carriers[41].

The variety of aircraft types now operating in New Zealand calls for a more fine-grained approach than used in previous assessments. Estimates in this report are based on a nominal block-hour variable cost for aircraft, using weight, engine type and size bands adapted from the FAA analysis of the US DOT surveys. Dividing the selected ADOC values into the more fine grained range of aircraft types also reduces the sensitivity of the overall results to errors in any particular band.

The bands are

- Super-Heavy Jet
- Heavy Jet (4 engine)
- Widebody Jet > 300 seats
- Widebody Jet <= 300 seats
- Narrowbody Commercial Jet > 160 seats
- Narrowbody Commercial Jet <= 160 seats
- Turboprop > 60 seats
- Turboprop > 20 seats and <= 60 seats
- Light Turboprop <= 20 seats

[40] (LEE et al., 2019)
[41] (FAA, 2022, Chapter 4 "Aircraft Operating Costs" Table 4-2)

- Business Jet (3 engine)
- Medium Weight Business Jet
- Light Business Jet

This report derives representative ADOC figures by interpolating a range of data sources including FAA statistics, some New Zealand operations and other publicly available data, adjusted where necessary to exclude fuel costs and converted to NZD.

Available statistics are generally from 2018 and 2019. When applied to benefits, ADOC is scaled by the NZ Producer Price Index[42] for the relevant year.

Selected ADOC figures are in the following ranges.

Aircraft Category	ADOC Range (NZD 2019)
Heavy Jet	4000 - 7680
Medium Jet	2600-2700
Large Turboprop	1600-1900
Light Turboprop	390-710
Medium Weight Business Jet	2300-3000
Light Business Jet	1100

Table 20 Selected Values for Non-Fuel Variable Aircraft Direct Operating Costs

A.5 Shorter Approaches

This benefits assessment compares approaches using conventional navigation, with PBN approaches on the same route (origin airport to destination runway). Savings attributed to PBN implementation are assessed based on the change in nominal flight path length when using PBN approaches instead of the conventional navigation approach.

The conventional navigation baseline assumes inbound flights proceed to the start of final approach using published navigation procedures, or under ATC surveillance control. Where the conventional arrival procedure is significantly different for flights from some directions or for faster aircraft (Napier, Nelson), an appropriate adjustment is applied.

The PBN baseline assumes that flights will follow the allocated PBN procedure to landing. At several locations (Christchurch, Nelson, Wellington, Auckland) various PBN arrivals have different final approach lengths. For the 2021-2023 period, the estimate is based on the PBN arrival actually used. The same pattern of use is applied when estimating for other years.

Christchurch has two alternative RNP approaches for international flights arriving from the west, with different final approach lengths. The model uses the approach assigned to the flight by ATC.

The model considers RNP AR approaches as a fixed additional distance saved over the alternative RNP APCH approach on the same route.

Table 21 lists the final approach length change, and any additional RNP AR savings for each airport runway.

[42] (Stats NZ, 2023a)

Airport	Runway	Conventional Final Approach (nm)	PBN Final Approach (nm)	Final Approach Savings (nm)	Additional RNP AR Savings (nm)	Remarks
NZAA	05R	12	12	0	0	All other approaches
		12	12	0	10.3	RNP AR X
		12	12	0	10.4	RNP AR Y from DAVEE
		12	12	0	7.9	RNP AR Y from east
		12	12	0	8.5	RNP AR Y from south
	23L	12	12	0	0	All other approaches
		12	12	0	3.8	RNP AR S (Interntational flights from the west)
		12	12	0	4.3	RNP AR S from south via DAVEE
		12	12	0	1.35	RNP AR S from south via PEPPE
		12	12	0	4	RNP AR U
		12	12	0	1.35	RNP AR V (from Bay of Plenty)
		12	12	0	12.8	RNP AR X
		12	12	0	13.5	RNP AR Y from south via DAVEE
		12	12	0	11.31	RNP AR Y from south via PEPPE
NZCH	02	13	8.2	4.8	0	All other approaches
		13	13	0	0	PBN from south and west
		13	8.2	4.8	7.4	RNP AR V from north
		13	8.2	4.8	4.2	RNP AR W from Wellington
		13	8.2	4.8	2	RNP AR Y from west
	11	8	8	0	0	No change. Previously no instrument approach
	20	12.1	8.1	4	0	All other approaches
		12.1	12.1	0	0	PBN from north and west
		12.1	8.1	4	6.7	RNP AR W from south
		12.1	8.1	4	5.9	RNP AR X from south
		12.1	8.1	4	5.9	RNP AR Y from southern Ausralia
		12.1	12.1	0	8.7	RNP AR Y from west
	29	8	8	0	0	No change. Previously no instrument approach
NZDN	03	10.3	12	-1.7	0	All approaches
	21	13.7	12.5	1.2	0	All approaches
NZGS	14	10	8.6	1.4	0	All approaches
	32	10	8	2	0	All approaches
NZHN	18L	12	8	4	0	All approaches
	36R	12	8	4	0	All approaches
NZNP	05	10	8	2	0	All approaches
	23	10	8	2	0	All approaches
NZNR	16	8	8	0	0	All other approaches
		10	8	2	0	From north
		15	8	7	0	Jet arrivals from south
	34	10	8	2	0	All approaches
NZNS	02	15	15	0	0	All other approaches
		15	11.5	3.5	0	From north east
	20	14.1	14.1	0	0	All approaches
NZNV	04	10	8	2	0	All approaches
	22	10	8	2	0	All approaches
NZPM	07	12	8	4	0	All approaches
	25	14.3	14.3	0	0	All other approaches
		14.3	14.3	0	19.4	RNP AR X from north
		14.3	14.3	0	17.6	RNP AR X from south
NZRO	18	12	11.4	0.6	0	All approaches
	36	12	11.8	0.2	0	All approaches
NZTG	07	10	8	2	0	All approaches
	25	10	8	2	0	All approaches
NZWB	06	10	10	0	0	no PBN approach
	24	14.4	14.4	0	0	All approaches
NZWN	16	11.8	11.8	0	0	All other approaches
		11.8	11.8	0	3.1	RNP AR X from north and west
		11.8	11.8	0	7.2	RNP AR X from south
	34	10	10	0	0	All other approaches
		10	10	0	6	RNP AR X from north
		10	10	0	3.2	RNP AR X from south and west

Table 21 RNP APCH and RNP AR Flight Path Reduction

Bibliography

Acuo. (2018). *New Southern Sky Cost Benefit Analysis Update*.

Air New Zealand Group. (2023). *Greenhouse Gas Inventory Report*. https://p-airnz.com/cms/assets/PDFs/air-nz-2023-GHG-inventory-report.pdf

Air Transport Action Group (ATAG). (2021). *Waypoint 2025*. https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

Baker, M. G., Wilson, N., & Anglemyer, A. (2020). Successful Elimination of Covid-19 Transmission in New Zealand. *N Engl J Med*, *383*(8), e56. https://doi.org/10.1056/NEJMc2025203

Boeing. (2023). *Commercial Market Outlook*. https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

Business Desk. (2023, 12 September). Air NZ faces major schedule changes as A320neo engines need early work. *Business Desk*. https://businessdesk.co.nz/article/markets/air-nz-faces-major-schedule-changes-as-a320neo-engines-need-early-work

Castalia. (2014). *Economic Analysis of National Airspace and Air Navigation Plan*.

Civil Aviation Authority of New Zealand. (2018). Concept of Operations 2023. In (2.0 ed.). Wellington: Civil Aviation Authority of New Zealand.

Civil Aviation Authority of New Zealand. (2021). *AC91-21 Operational Approvals - Performance-Based Navigation*. Retrieved from https://www.aviation.govt.nz/assets/rules/advisory-circulars/AC091-21.pdf

Edouard Mathieu, H. R., Lucas Rodés-Guirao, Cameron Appel, Charlie Giattino, Joe Hasell, Bobbie Macdonald, Saloni Dattani, Diana Beltekian, Esteban Ortiz-Ospina and Max Roser. (2020). *Coronavirus Pandemic (COVID-19)*. OurWorldInData.org. https://ourworldindata.org/coronavirus

FAA. (2022). *Benefit-Cost Analysis*. Federal Aviation Administration (FAA). https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost

Federal Aviation Administration. (2023). Airwothiness Directives; International Aero Engines, LCC Engines. In *Notice of Proposed Rule Making (NPRM)*.

Heart Aerospace. (2022). *Heart Aerosapce unveils new airplane design, confirms Air Canada and Saab as new shareholders* https://heartaerospace.com/heart-aerospace-unveils-new-airplane-design-confirms-air-canada-and-saab-as-new-shareholders/

IATA. (2023). Aviation Fuel Supply Model Agreement. In (5.1 ed.). Montreal - Geneva: IATA.

ICAO. (2007). *A36-23: Performance Based Navigation Global Goals*. 37th Assembly Resolutions: ICAO Retrieved from https://www.icao.int/safety/pbn/pbn%20references/assembly%20resolution%2036-23_%20pbn%20global%20goals.pdf

ICAO. (2013). *A37-11 Performance-Based Navigation Global Goals*. ICAO 38th Assembly: ICAO Retrieved from https://www.icao.int/safety/pbn/PBN%20references/Assembly%20Resolution%2037-11_%20PBN%20global%20goals.pdf

International Air Transport Association. (2023). *Global Outlook for Air Transport*. https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report/

Khatwa, R., & Helmreich, R. L. (1999). Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight. *Flight Safety Digest*, *17*(11), 1-56. https://skybrary.aero/sites/default/files/bookshelf/1542.pdf#page9

Kung, S., Hills, T., Kearns, N., & Beasley, R. (2023). New Zealand's COVID-19 elimination strategy and mortality patterns. *Lancet*, *402*(10407), 1037-1038. https://doi.org/https://doi.org/10.1016/S0140-6736(23)01368-5

LEE, M., LI, L. K. B., & SONG, W. (2019). Analysis of direct operating cost of wide-body passenger aircraft: A parametric study based on Hong Kong. *Chinese Journal of Aeronautics*(32), 1222-1243.

Mahino Consulting. (2017). *New Southern Sky (NSS) Performance Based Navigation (PBN) Metrics Analysis 2017*. Civil Aviation Authority of New Zealand.

Mahino Consulting. (2021). *New Southern Sky Benefits Assessment*.

Ministry of Transport. (2012). *National Airspace Policy of New Zealand*. Wellington: New Zealand Government

New Zealand Government. (2022a, 12 May 2022). *Fully Open Border and Immigration Changes Speed Up Economic Growth*. https://covid19.govt.nz/news-and-data/latest-news/fully-open-border-and-immigration-changes-speed-up-economic-growth/

New Zealand Government. (2022b). *History of the Covid-19 Alert System*. Retrieved from https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/

New Zealand Government. (2022c). *History of the New Zealand Covid-19 Protection Framework (traffic lights)*. Retrieved from https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-protection-framework-traffic-lights/

New Zealand Government. (2022d). *New Zealand Border to Reopen in Stages from 27 February*. https://covid19.govt.nz/news-and-data/latest-news/new-zealand-border-to-reopen-in-stages-from-27-february/

Poll, D. I. A., & Schumann, U. (2021a). An estimation method for the fuel burn and other peformance characteristics of civil transport aircraft during cruise: part 2, determining the aircraft's characteristic parameters. *The Aeronautical Journal*, *125*(1284), 296-340. https://doi.org/10.1017/aer.2020.124

Poll, D. I. A., & Schumann, U. (2021b). An estimation method for the fuel burn and other performance characteristics of civil transport aircraft in the cruise. Part 1 fundamental quantities and governing relations for a general atmosphere. *The Aeronautical Journal*, *125*(1284), 257-295. https://doi.org/10.1017/aer.2020.62

Radio New Zealand. (2020). *Sounds Air aims to offer first regional zero-emission flights*. Radio New Zealand. https://www.rnz.co.nz/news/business/427098/sounds-air-aims-to-offer-first-regional-zero-emission-flights

Reserve Bank of New Zealand. (2023). *Exchange Rates and TWI - B1 Daily*. Reserve Bank of New Zealand. Retrieved 20 September from https://www.rbnz.govt.nz/statistics/series/exchange-and-interest-rates/exchange-rates-and-the-trade-weighted-index

RNZ/ABC. (2021). Quarantine-free travel for New Zealanders into Queensland revoked. *Radio New Zealand News*. https://www.rnz.co.nz/news/world/437104/quarantine-free-travel-for-new-zealanders-into-queensland-revoked

Singleton, M. (2023). Central Otago Project Update. https://www.centralotagoairport.co.nz/uploads/images/Dec-2023-Central-Otago-Project-edm.pdf

Stats NZ. (2022). *Border Crossings Highest in Two Years*. Stats NZ. https://www.stats.govt.nz/news/border-crossings-highest-in-two-years/

Stats NZ. (2023a). *Business Price Indexes: September 2023 quarter - CSV*

Stats NZ. (2023b). *Consumer Price Index* https://www.stats.govt.nz/assets/Uploads/Consumers-price-index/Consumers-price-index-September-2023-quarter/Download-data/consumers-price-index-september-2023-quarter.xlsx

The Treasury. (2023). *Half Year Economic and Fiscal Update*. https://www.treasury.govt.nz/sites/default/files/2023-12/hyefu23.pdf

US Energy Information Administration. (2023). *U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Price FOB*. Retrieved 20 September from https://www.eia.gov/dnav/pet/hist/EER_EPJK_PF4_RGC_DPGD.htm

Waka Kotahi. (2023). *Monetised Benefits and Costs Manual*. Retrieved from https://www.nzta.govt.nz/assets/resources/monetised-benefits-and-costs-manual/Monetised-benefits-and-costs-manual.pdf

World Resources Institute, & World Business Council for Sustainable Development. (2004). *The Greenhouse Gas Protocol*. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf