Impact of Future Zero Emissions Aircraft on Nelson Airport Runway Needs

29th August 2022
(Report ZEA00045)

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Executive Summary

As the awareness of the impacts of polution on the environment become better known, the aviation industry is facing significant pressure to decarbonise and eliminate polutting emisisons. The challenge should not be underestimated as due to the fundamentals of aviation the technology hurdle to decarbonise aviation is of the order of 20 times more difficult than the equivalent effort required to decarbonise the automobile.

Of the technologies being proposed for the transition to zero emissions flight, those gaining the most focus are battery-electric, and gaseous and liquid hydrogen fuel used with fuel cells and gas turbines. Application of these technologies is proposed both via conversions of existing aircraft as well as purpose designed aircraft fully adapted to these new propulsion systems. The introduction of such zero emissions aircraft technology has been proposed for as early as 2026, but it is more likely in the 2028-2030 timeframe, with large scale introduction occuring in the mid-2030's.

Reviewing existing runway use at Nelson Airport a key aircraft type is the ATR72 aircraft which represents 30% of large aircraft movements. This aircraft requires 1315m length of runway at maximum weight and ideal weather conditions, verses the 1347m runway available at Nelson Airport today. This gives very little margin for common variations in environmental conditions. Indeed analysis of the ATR72 Flight Crew Operations Manual and Air New Zealand operations shows that this aircraft type is already highly susceptible to payload off-loading when operated from Nelson Airport‘s short runway from weather events as common as a warm summer's day.

Analysis of future purpose-designed zero emissions aircraft indicates that all of the technologies choices will likely result in an increase in the maximum take-off weight compared to a traditional aircraft like the ATR72 for the same passenger capacity. For battery-electric and gaseous hydrogen the technology limitations are such that not only will the overall aircraft weight increase significantly, but the passenger capacity, cruise speed and range may be inferior to existing aircraft. Only aircraft based on liquid hydrogen technologies are likely to allow a direct replacement of current aircraft. Analysis shows purpose designed zero emissions aircraft types to replace the ATR72 will likely require between 1373m and 1530m of runway length, making all of them incompatible with Nelson Airport's current 1347m runway.

Conversions of existing aircraft with zero emissions propulsion systems are likely to occur as an interim solution until the introduction of all new purpose designed types is possible. These converted aircraft may have the same maximum weight as the pre-conversion aircraft, but will have a reduction in both passenger capacity and a lower payload fraction than the original baseline aircraft. This will make them much more weather sensitive to short runways like Nelson Airport's runway. Analysis shows that a small weather variation that might only require a 1% reduction in payload for an ATR72 with Nelson Airport's short runway could require between 10-18% payload reduction on a converted zero emissions aircraft type. Such sensitivity to short runways will likely require periodic passenger off-loading, making the availabiltiy of service for these converted types from Nelson Airport's runway unreliable to the point of being uneconomic.

Purpose designed zero emissions aircraft, whilst requiring a longer runway length than converted types will have less sensitivity to payload fraction, albeit analysis indicates they could still require a 6-8% payload reduction in weather conditions where an ATR72 only requires a 1% reduction. An extension of Nelson Airport's runway to 1510m would not only allow both converted and purpose designed zero emissions aircraft to use Nelson Airport, it would provide sufficient runway length to give margins for common occurance weather events to ensure service reliability and economic operations.

Beyond the day-to-day operability of the future zero emissions aircraft types using Nelson Airport‘s runway, the necessity to ensure the runway length is sufficient to maintain the relevance of Nelson's maintenance base operations for future zero emissions aircraft should also be considered. Without runway extension, some zero emission types will not be able to use the airport, and other types will require empty positioning flights which may promote maintenance work to be moved elsewhere. Additionally, care in the investment decisions for refuelling and recharging infrastructure for new aircraft types should be taken to avoid the risk of over investing in facilities that could become redundant, short lived or under-used.

Finally, irrespective of aircraft technology type, the reader is reminded that certified aircraft limits should be considered as minimums to avoid undue safety risk rather than treated as a point beyond which safety enhancement is unnecessary. Nelson Airport today has one of the shortest runways in the world for the frequency of ATR72 and Q300 movements it handles. As 67% of all recent fatal aircraft accidents have occured in the flight phases associated with the runway, any investment to increase the runway length at Nelson Airport should be strongly supported as this will inherently increase the safety for all stakeholders and reduce the risks of operations.

Key Points

- Nelson Airport's short 1347m length runway already penalises economic operations of existing aircraft types like the ATR72 when relatively common occurrence weather conditions occur.
- Nelson Airport's current runway will not be suitable for likely upcoming replacement new design zero emissions aircraft without an extension to the proposed 1510m runway length.
- Future zero emission aircraft will have lower payload flexibility and hence will have more frequent and higher penalties from common weather conditions combined with Nelson's short runway.
- Operations into Nelson Airport for converted zero emissions aircraft types may be uneconomic due to the unreliability of service caused by the short runway, weather and payload flexibility combination.
- Introduction of initial zero emissions types should occur by the end of the decade, with wide spread introductions in the mid-2030's.
- The 1510m runway extension will be important to maintain the relevance and viability of maintenance services and employment at the Airport for future zero emissions aircraft types.
- On a purely safety basis, as 67% of fatal accidents are linked to flight phases associated with runway use, increasing the runway length to increase safety margins is highly recommended.

CONTENTS

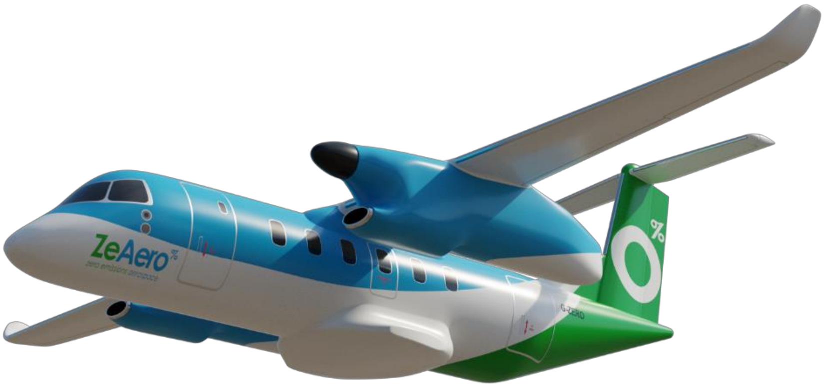
NOMENCLATURE AND ABBREVIATIONS

Term	**Definition**
AKL	Auckland Airport code
Aspect ratio	The ratio of wingspan to average wing chord, which affects the aerodynamic efficiency of an aircraft.
Balance of Plant	The complementary equipment necessary to integrate a fuel cell stack into a usable power module, including compressors, cooling, hydrogen management, etc.
Drop Tank	A fuel tank mounted externally to the airframe, most commonly used by military aircraft to carry additional fuel, which can be (in some applications) dropped from the aircraft when no longer needed.
EASA	European Aviation Safety Authority
FAA	Federal Aviation Administration (USA)
FCOM	Flight Crew Operations Manual
GH2	Gaseous Hydrogen
H2	Hydrogen
ISA	International Standard Atmosphere
LH2	Liquid Hydrogen
MLW	Maximum Landing Weight - a certified weight limitation for the aircraft for landing, which is usually set by the structural capabilities of the airframe.
MTOW	Maximum Take-Off Weight - a certified weight limitation for the aircraft for take-off, which is usually set by the structural capabilities of the airframe.
NSN	Nelson Airport code
Part-23	An aircraft certification category limiting the MTOW to no more than 19,000lbs and an aircraft having capacity for no more than 19 passengers.
RESA	Runway End Safety Areas
SAF	Sustainable Aviation Fuel (sometimes Synthetic Aviation Fuel)
Sustainable Aviation Fuel	Sustainable Aviation Fuel is an equivalent chemistry to Jet Fuel, allowing it to be used in aero engines certified for its use, but made renewable sources such as used cooking oil, municipal waste and woody biomass.
Synthetic Aviation Fuel	A subset of Sustainable Aviation Fuels, made using the Fischer–Tropsch process which is a collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons, such as Jet Fuel.

1. STATEMENT OF EXPERTISE

ZeAero$^{\%}$ (*Zero Emissions Aerospace Limited*) is a UK aerospace company founded in 2019 for the express purpose of developing zero emissions aviation technology and new green aircraft designs to enable practical emissions free flight. Whilst a relatively young company, the company's key staff members have strong backgrounds in aircraft and aero-engine engineering and development, with significant past experience coming from companies such as Airbus, Rolls-Royce and BAE SYSTEMS.

The main author of this paper has over 25 years of aircraft research and aircraft development experience, with degrees in Mechanical Engineering and Aerospace Engineering up to doctorate level. He has previously held Executive level Engineering roles at one of the world's main aircraft manufacturers and has been involved in the design and certification of several aircraft types. He is a Member of the Royal Aeronautical Society, a Chartered Engineer, an award winner from the Royal Aeronautical Society and a previous Spitfire Mitchell Memorial scholar.



2. INTRODUCTION

Aviation makes many very important contributions to modern society. Whether it is the effective enablement of the economy, through the transport of goods and links for trade, or through generating new opportunities for connection and progression. It also cannot be understated aviation's role in creating connectivity across the globe thereby bringing greater understanding between groups of people, nor the power of community it enables by simply bringing family and friends together. For isolated or remote regions, aviation has a big role to play. ICAO(1) estimates that 8% of global GDP and 40% of physical trade by value are supported by aviation. This figure is even greater for geographically remote locations such as New Zealand. No one in New Zealand has not benefited in one way or another from the positive aspects that aviation brings.

This is not to say that everything is rosy for aviation, and the biggest challenge the industry faces is how to mitigate the pollution generated by current aircraft types powered predominantly by hydrocarbon Jet Fuel. Today aviation represents less than 3% of global CO_2 emissions, but this is growing with the increases in air traffic and NO_X emissions and contrail effects have to be managed as well. The technical challenge to reverse this is significant.

Before being in a proper position to comment on aviation pollution levels one must first understand two important aspects. The first aspect is the massive improvement in fuel efficiency that the aircraft industry has achieved in the last 60 years, Figure 1, with an almost 80% improvement aircraft fuel efficiency and CO_2 emissions reduction since the beginning of the jet age(2). To achieve these improvements the latest generation of aero-engines are achieving efficiency levels approaching 40%(3). In contrast the efficiency of a combustion engined car is around half this, being somewhere between 16% to 25% only(4). The second aspect is that the energy intensity of flight is typically an order of magnitude higher than ground-based transportation forms, with ground-based transport also being less weight critical than airborne transportation.

This combination of existing high efficiency and high energy intensity requirements means it is a significantly greater technical challenge to decarbonise aviation than it was the automobile. Something that has been overlooked by some pundits who assumed the Tesla age for the automobile would simply transfer into aerospace. A very simplistic sum would be to multiply the existing 2x efficiency superiority of aviation technology over automotive technology with the 10x energy intensity required for flight versus ground transport; giving a 20x greater technical challenge to decarbonise aviation compared to the car. This 'sum' highlights the core of the zero emissions aviation challenge.

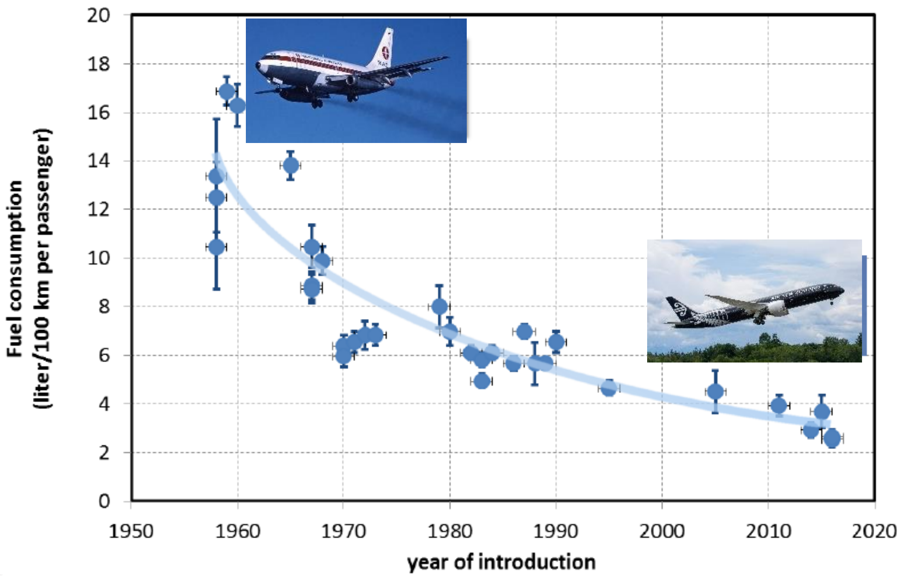


Figure 1: Improvement in Aircraft Fuel Efficiency (and CO2 emissions) since the beginning of the Jet Age.
Source: IATA 2050 Vision Report (2)

Whilst aviation today contributes a relatively small amount of the global CO_2 emissions, contributing less than 3% of global man-made CO_2 emissions, it creates these emissions at altitude, and it also creates other atmospheric pollutants in the form of NO_X and contrails. Collectively the effects are assessed to contribute to between two and three times the global warming influence of just the CO_2 aviation emission volumes alone. Combining this with the increased air transport demands to enable economic growth and connectivity, if no step change in aviation technology is made to reduce emissions, then a significant overrun in aviation emissions versus the industry targets will occur by 2050, as highlighted in Figure 2(5).

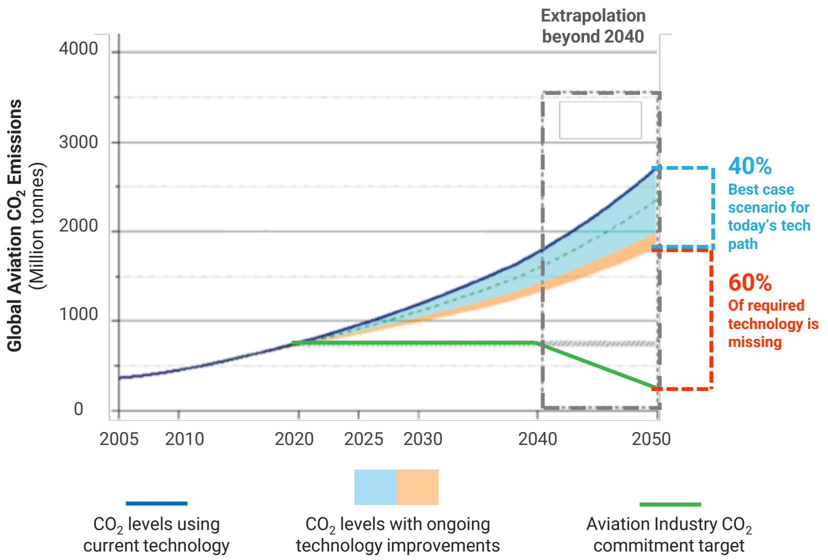


Figure 2: Aviation CO_2 emissions trends and the Technology Gap to reach aviation emissions reduction targets by 2050. *Sources: Carbon Brief and IATA 2050 Vision Report* (5).

A very short-sighted view of some is to simply propose to restrict all aviation growth. This ignores the consequences of restricting the population from the 40% of high value trade, the penalties in not being able to economically connect with others, and particularly the penalty of disconnection for the more remote parts of the country and wider world. All these consequences are a high penalty to pay and unnecessary when technical solutions are becoming available.

The more preferrable route, and a route that protect jobs, encourages growth and protects the environment concurrently is to anticipate and prepare for Zero Emissions aircraft types. Part of that anticipation includes ensuring that the appropriate infrastructure is in place in time for these new classes of emissions free aircraft. This will involve preparing the necessary runway and refuelling / recharging infrastructure.

Key Points

- Aviation is a very significant driver of economic prosperity and community connectivity benefits.
- Aviation's significant historic improvements in efficiency and emissions, combined with the energy intensity of flight, makes the elimination of emissions 20x more challenging than for automobiles.
- To avoid aviation emissions growth new zero emissions aircraft technologies are anticipated.
- Cutting off our community from the benefits of aviation is unnecessary and penalising when zero emissions technology solutions are on the horizon.
- Preparations for zero emissions should also anticipate the airport infrastructure needs.

3. FUTURE ZERO EMISSIONS AIRCRAFT TECHNOLOGY

In Section 2 we highlighted that the technical challenge to decarbonise aviation is of the order of 20x more challenging than that faced by Tesla when it moved to decarbonise the automobile at the start of the century. The combination of already high efficiency levels of modern aircraft with the greater energy intensity of flight means consequentially that aviation decarbonising solutions are more complex and all of the solutions will have implications for the supporting infrastructure.

Aviation is an extremely weight and drag (volume) sensitive endeavour, and to decarbonise aviation the influence of alternative energy storage and propulsion systems must consider the impacts they have on these parameters. Placing the bar high is Jet Fuel which powers the majority of our commercial flights today as it is a very effective energy storage medium for flight. Factors favouring Jet Fuel include:

- It has a good specific energy of 43.15 MJ/kg.
- It is relatively inflammable when not being used.
- It can be stored on the aircraft across the range of operating temperatures without many special measures, often being stored within the wings, which otherwise are an unused volume.
- It can be transported easily to point of use from storage or refineries.
- The time taken to refuel the aircraft is relatively short

Contrast this with the State-of-the-Art for batteries, which is the most common solution for cars. The problems with batteries for flight include:

- They have an extremely poor specific energy of 0.7 MJ/kg (the today Tesla level of achievement), noting that this is only 1.6% the specific energy of Jet Fuel!
- High temperature Li-ion thermal runaway fires are a specific safety issue, which by design cannot be allowed to occur in flight. This is more critical than for an automobile.
- They have very short useful aircraft life, typically requiring replacement after 1000-1500 flight cycles, which is less than 6 months of regular airline use.

This highlights the level of challenge that zero emissions aircraft designers face in finding alternative aviation energy storage solutions, compared to other sectors.

This is not to say that aircraft designers do not have solutions, nor have explored a number of different possibilities for zero emissions flight. Figure 3 highlights the most commonly recognised emission reduction energy storage and propulsion solutions that have been actively investigated over the preceding decades, and the pros and cons of these different solutions.

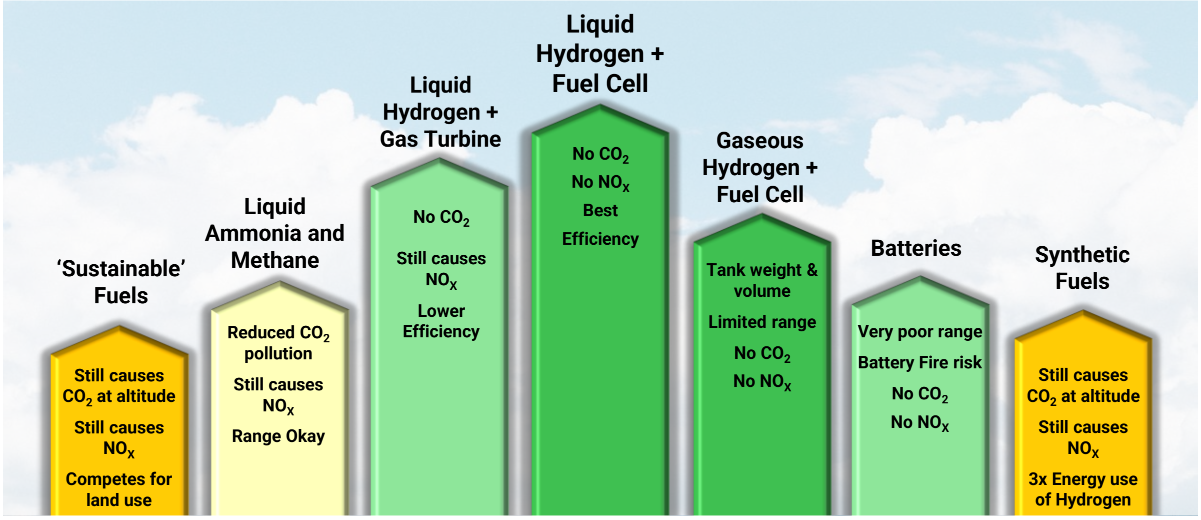


Figure 3: Pros and Cons of different energy storage and energy conversion technologies for Zero and Low Emissions Aviation, with highlighted CO_2 and NO_X improvement, pros and cons. © *ZeAero*%

It should be noted for Figure 3 that Synthetic and ‘Sustainable Aviation Fuels’ do provide some alleviation of the polluting emissions caused by aviation and these fuel solutions have the potential big advantage to be ‘dropped in’ to existing aircraft designs. However using these fuels still creates CO_2 emissions at altitude, where the damage is greater than the CO_2 capture at ground level where these fuels are made. Their use also still results in NO_X pollution creation and contrail formation. These fuels are a necessary positive step in the decarbonisation journey for aviation but should always be considered as an interim step for longer-term aviation pollution elimination, rather than a final step. Liquid Methane and Liquid Ammonia are some other fuels that potentially could reduce but not eliminate aviation emissions. However, given the investment levels to make these alternative fuels workable in practice and the fact they do not give true zero emissions flight, the likelihood of them progressing to widespread commercial use is low, hence they will not be further discussed in this paper.

This leaves Hydrogen and Battery energy storage as the most likely candidates for zero emissions commercial aviation, and these will be discussed in more detail leading to a discussion on how they affect future runway needs.

3.1 BATTERY ELECTRIC AIRCRAFT

After the success of Tesla in disrupting the automobile market, many believed that it was only a short amount of time before the same technology would disrupt the Aviation market. Indeed, several big players such as Airbus with their E-FanX project and Rolls-Royce with their Accel project have made significant investments into exploring the potential of battery electric technology for flight.

Figure 4: Rendering of the proposed Heart ES-19 aircraft.
Source: Heart Aerospace, 2022, heartaerospace.com**.**

The assumed potential of battery-electric flight in the late 2010’s resulted in an explosion of different aircraft projects being started, with the Heart ES-19(6), Figure 4, which has been tentatively ordered by Sounds Air in New Zealand and the Eviation Alice(7), Figure 5, being two well-known examples.

The very, very big difficulty these developments face however is the very poor specific energy of batteries in comparison to Jet Fuel, as today batteries only achieve 3% the specific energy of Jet Fuel in the best case. NASA’s own Expert panel for ‘*Reducing Global Carbon Emissions*’ for commercial aircraft analysing the fundamental science behind battery powered flight predicted that it will be at least 30 years before batteries might propel aircraft bigger than small, short-range business aircraft(3). Indeed the published range of the Heart ES-19, without any mandatory weather safety reserves, is only 216 nautical miles(6) which would require a reduction in existing CAA defined safety margins to even fly the Nelson-Wellington route commercially. It is notable that as the recognition of the specific energy limitations of batteries has become better understood that many zero emissions aircraft projects have cancelled battery-electric developments and moved instead to hydrogen technologies, one such example being Project Fresson(8) in the UK.

Figure 5: Rendering of the Eviation Alice aircraft.
Source: Eviation, 2022, https://www.eviation.co/media/.

The Eviation Alice, Figure 5, on the other hand is a smaller 9-passenger aircraft aligning with the recommendations of the NASA research closer than the Heart ES-19 development. Whilst this smaller aircraft would not define the runway needs for Nelson airport, it is a very important reference as it is in the most advanced stage of development of all commercial battery-electric aircraft types (first flight due in 2022) and hence it provides the most realistic data point for the technology. Tellingly the Eviation Alice has been through three major redesigns to reach its current status, with each redesign increasing the aircraft weight and reducing the aircraft range, with the implication being that this was a consequence of battery performance. It therefore makes a very useful comparison reference point to an equivalent Jet Fuel powered aircraft to provide an understanding of how the application of battery-electric propulsion would affect the typical sizes of aircraft that Nelson Airport might expect to operate in the future.

In Figure 6 we compare key parameters of the Eviation Alice with the Pilatus PC-12, which with 1,700 aircraft produced is the most popular and comparable Jet Fuel powered 9-passenger aircraft in this class in production today. In New Zealand, a well-known operator of the Pilatus PC-12 aircraft is Sounds Air.

Parameter	Eviation Alice	Pilatus PC-12	Alice vs PC-12
MTOW	16,500lbs	10,450lbs	+58%
Passengers	9	9	Same
Crew	1-2	1-2	Same
Wingspan	19.2 m	16.28 m	+18%
Battery or Fuel	8,200lbs	2,704lbs	+203%
Cruise Speed	220 knots	290 knots	-24%
Maximum Range*	440nm (*no payload*)	1803nm (*800lb payload*)	-75%

Figure 6: Comparison of Key Parameters of the Eviation Alice and Pilatus PC-12.
***Note Maximum Range includes nominal IFR reserves.**
Sources: www.pilatus-aircraft.com and www.eviation.co websites

Key things to note from the Figure 6 comparisons are the 58% higher MTOW of the Eviation Alice aircraft for a range that is 75% worse, and is specified with zero payload for the Alice. This is a direct consequence of the problem of poor battery specific energy. Even to reach this performance point the designers of the Eviation Alice have used many 'design tricks' by giving the aircraft an extremely high aspect ratio wing (which improves aerodynamic efficiency) with an 18% longer wingspan, by neglecting payload from the range equation, and reducing the cruise speed (as drag is proportional to the square of the velocity of the aircraft). All these actions are attempts to reduce the energy requirement of the aircraft to compensate for the poor performance of the batteries. A similar beneficial design choice made by the Alice designers is the high proportion of carbon-fibre use in the Alice airframe, even though this is an expensive solution, to try to make more available aircraft weight for carriage of batteries. These design choices have consequences, for example the reduction in cruise speed has an economic penalty that the aircraft can complete less revenue missions in the same timescale compared to the Pilatus PC-12.

Even with latest reductions in published performance there remains a real risk that as the Eviation Alice has not conducted its first flight and has not been certified, that these performance numbers for the Alice will deteriorate further before the first aircraft is finally delivered to a customer.

The big take away from this aircraft comparison, in terms of larger passenger aircraft for Nelson airport that might use battery-electric propulsion is a large increase in MTOW will be required for battery-electric aircraft types. An increase in MTOW is usually associated with an increase in required runway length, and the implications will be discussed further in Section 4.

Due to the battery limitations as NASA(3) projected it is likely that this type of technology will be restricted to smaller aircraft types rather than for everyday airline use until the 2050's or later when battery specific energy levels catch up. Even so it would still be prudent to anticipate the needs of this technology when making any runway infrastructure changes.

3.2 HYDROGEN POWERED AIRCRAFT

With the realisation that battery powered aircraft are unlikely to be practical for most airline missions, a more in-depth review of other options has led many organisations to consider Hydrogen to be the most likely Zero Emissions technology for aircraft. Most prominent amongst the proponents for hydrogen flight is Airbus(9).

Whilst most people will be aware that hydrogen was one of the earliest enablers of manned flight being used in some very early airships, many are probably unaware that hydrogen powered aircraft are not new with the first demonstrator aircraft taking flight in 1956 in the US. However, the effectiveness and low cost of Jet Fuel, plus the investment required to make hydrogen powered aircraft mainstream never really allowed the technology to progress beyond test flights. This was however at a time when aircraft emissions were barely a consideration in technology choices.

The benefits of hydrogen over the other energy storage choices available to aircraft designers are:

1. It has a very high specific energy of 120MJ/kg (which is ~3x Jet Fuel, ~170x Batteries)
2. It produces no CO_2 when burnt
3. It can be used to power Fuel Cells, which have very high efficiency levels.

Hydrogen however has one particular disadvantage for aviation, which is its volumetric energy density, as 1kg of hydrogen at standard ground atmospheric conditions would occupy a volume of 11,200 litres, whereas 1kg of Jet Fuel occupies a volume of 1.25 litres in the same conditions. This means for one unit of energy, hydrogen in these conditions would require 3,200 times more volume than Jet Fuel, which would be catastrophic for the aircraft drag. Therefore, the aircraft designer has two realistic options:

1. Store the hydrogen as a gas at high pressure, with 700 bar being a typical use pressure. This can reduce the volume penalty to 9.1x that of Jet Fuel but with the penalty that it requires heavy tanks which weigh much more than the fuel they store. Also, the high-pressure of the gas creates a safety challenge in itself.
2. Store the hydrogen as a cryogenic liquid, which requires storage at -253°C. This reduces the volume penalty to 3.8x that of Jet Fuel and can be achieved at low pressures, but requires special insulated tanks and systems to avoid wasteful fuel boil off and other issues such as oxygen liquefaction.

Both solutions are being proposed by various companies for aircraft use, including Universal Hydrogen(10) proposing the use of high-pressure hydrogen gas, Figure 7, and Airbus(9) proposing the use of liquid hydrogen.

Figure 7: Universal Hydrogen illustration of proposed Dash-8 Aircraft hydrogen conversion using gaseous hydrogen capsules. *Credit: Universal Hydrogen.*

What needs to be recognised from an infrastructure point of view, is that whilst the aircraft gets more energy per kilogram from hydrogen, the aircraft storage takes far more weight and comes with a volume penalty affecting drag and/or payload as the fuel takes up more (useful) space in the aircraft than Jet Fuel. Hydrogen also requires a dedicated tank and cannot be stored as simply in the wing structure where Jet Fuel is traditionally stored in most aircraft with an extremely minor weight impact. In terms of the state-of-the-art, the tank storage fraction of hydrogen (the proportion of fuel weight to the total tank weight plus fuel weight) is between 6-10% for high-pressure hydrogen gas, and 28-35% for liquid hydrogen solutions.

Luckily the specific energy advantage of hydrogen over Jet Fuel is roughly 3 times better, so the mass of hydrogen required for an identical aircraft will be lower. However, one can quickly see that the benefit is quickly over-ridden by the challenge of storage volumes and weight. This is without the difficulties of providing a hydrogen specific fuel system to safely operate an aircraft using such a fuel.

From an infrastructure point of view, the hydrogen storage penalty will usually result in a heavier aircraft compared to a jet fuel aircraft for the same payload. The level of the penalty for the hydrogen aircraft are dependent on energy conversion design choices. The lower mass of required hydrogen due to its specific energy also has a significant consequence when operating into restricted runways, because it reduces the fuel weight fraction of the aircraft which will be discussed in Section 4.

3.3 HYDROGEN BURN OR FUEL CELL

Returning to Figure 3 it was highlighted that there are two main routes to convert hydrogen into propulsive energy on the aircraft. One is to modify a conventional gas turbine, used by most commercial aircraft today, the other being to introduce fuel cells to convert the hydrogen into electrical energy which is then used to power electric motors.

Very briefly, as it is not the main purpose of this report, the implications of the two choices are:

> ***Hydrogen burn*** – as a propulsion source the gas turbine is lightweight and easy to scale to larger power units, meaning there is no theoretical limit on aircraft size. The gas turbine also remains effective at high altitudes. The disadvantages are the efficiency of the gas turbine will be less than that of a fuel cell, and NO_X is still formed in the hydrogen burning process along with particulates that can enable contrail formation. This means it is not a fully zero emissions solution.

Hydrogen Fuel Cell – the efficiency levels are higher than gas turbines, and no NO_X or particulates are formed during operation, so it is possible to be a completely emissions free solution. The negatives are the Fuel Cell system with its enabling balance of plant are significantly heavier than a comparable gas turbine, easily being double the weight. Further operation above 25,000ft is technically challenging due to the air flow requirements for the fuel cells combined with the air density at altitude. Fuel cell technology is also still maturing, so it is not yet at the same level of maturity as gas turbines, but a benefit of this is it probably means fuel cells have greater untapped improvement potential.

The consequences of these facts are a hydrogen fuel cell aircraft will have a higher efficiency but will be restricted to lower altitudes where the energy consumption is higher, and the propulsion system will be of higher weight due to the mass of the fuel cell system. As a comparison a state-of-the-art fuel cell system Power-to-Weight is expected to be around 2.0kW/kg, whereas a representative legacy PT6A-67D gas turbine delivers around 4.1kW/kg. The hydrogen gas turbine in contrast will enable operations at higher altitudes and scale to larger power unit sizes and larger aircraft types, but with worse fuel efficiency, and this is compounded by the penalty of hydrogen storage and fuel systems meaning the aircraft application will still be heavier than a Jet Fuel aircraft.

3.4 AVIATION GREEN TECHNOLOGY APPLICABILITY

The aviation industry certainly has not reached the point where it can conclusively say one green or zero emissions technology will dominate over all others, and certainly not in the way the gas turbine in the form of jet and turbo-prop engines has dominated in the last 60 years of aviation. In fact, there is a good chance that there will be a fragmentation of technology application dependent on the market segment, as predicted in Figure 8.

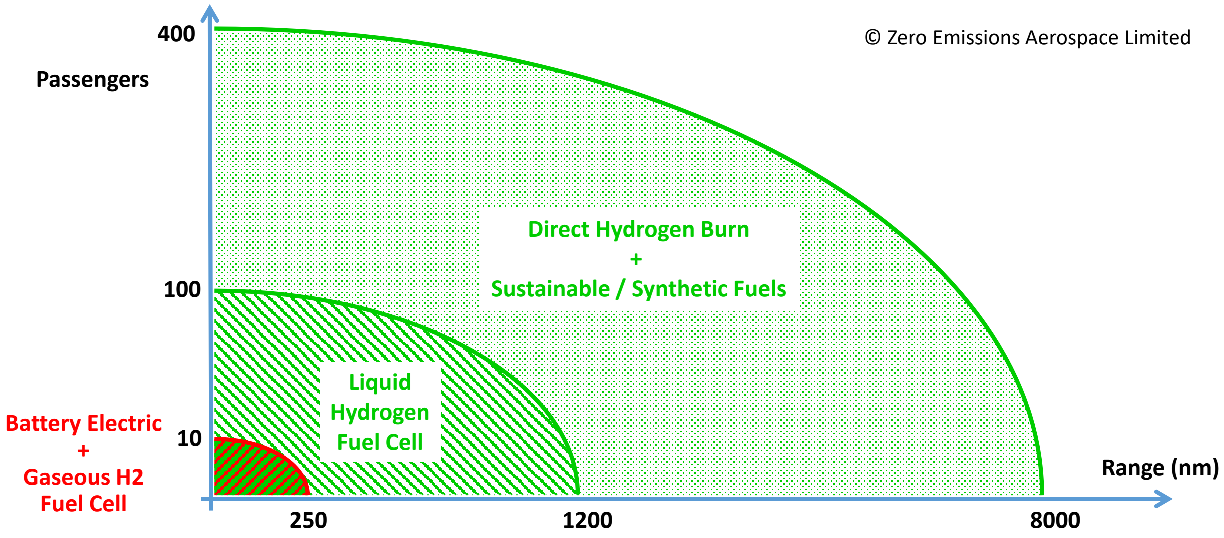


Figure 8: Possible Fragmentation of Green Aviation Technology applications in 2030-2040. © _ZeAero%_

This would see battery-electric technology for the next decades being limited to light and very short-range aircraft until battery technology improves to a level where it can become relevant. Regional aircraft would be preferably hydrogen fuel cell powered, due to the efficiency potential and complete removal of emissions of fuel cells, although hydrogen fuelled gas turbines are also possible. For medium and longer-range missions then the power-to-weight and scalability of gas turbines will still be needed, ideally fuelled by hydrogen to minimise in-flight emissions. SAF will be needed as an interim emissions improvement, particularly for long range missions, and to allow the time necessary to produce the replacement aircraft needed to move from Jet Fuel to other energy sources as this could take more than a decade.

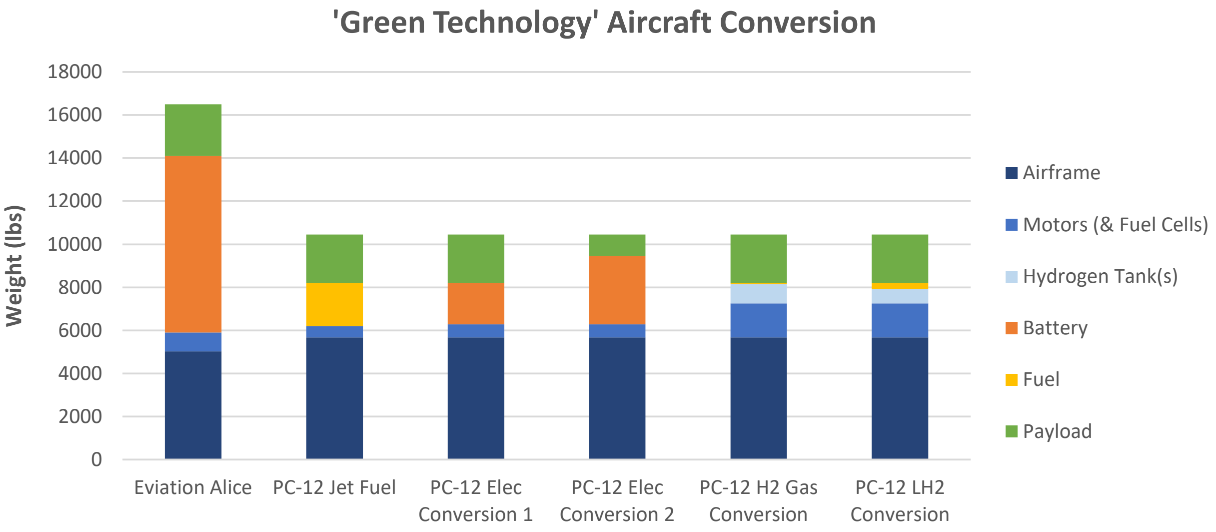
3.5 ZERO EMISSION AIRCRAFT CONVERSIONS

One important consideration for infrastructure operators is how these new technologies will be introduced into the in-service aircraft fleet, as both new purpose-designed clean-sheet aircraft and propulsion conversions of existing aircraft are being proposed by various companies.

The clean-sheet designer has more tools available to them to try to mitigate the additional weight that these new green energy storage solutions will add to a purpose-designed aircraft. This could be by using weight saving technology on other parts of the aircraft to compensate, or simply making a bigger aircraft for the same number of passengers. The Eviation Alice as seen in Section 3.1 applies both approaches, with a 60% increase in size and extensive use of lightweight composites in the airframe. The downside of an all-new purpose-designed aircraft approach is it takes longer and is higher risk than converting an existing design.

Consequentially with the intent to bring zero emissions solutions to the market earlier, many companies are proposing to convert old and existing aircraft designs for reuse with the new technology. The problem this approach faces is these aircraft are structurally designed and certified to a MTOW (maximum take-off weight) already and in most circumstances the MTOW cannot grow. As the zero emissions propulsion systems are larger and heavier, the number of passengers, payload and fuel load consequentially have to be reduced. This has important infrastructure consequences which shall be discussed in Section 4.

Taking the Eviation Alice depicted in Figure 6 as an example of a future purpose-designed zero emissions aircraft, in Figure 9 we compare it with the Jet Fuelled Pilatus PC-12, and analytically perform a weight breakdown analysis for the baseline PC-12 and different battery-electric and hydrogen conversions of the PC-12. Note that the predicted range capability will vary with the implementation of each technology, and this is analysed and noted under each aircraft variant weight breakdown in the figure.



400	**1402**	**29**	**47**	**110**	**1011**	**Max Payload Range (nm)**
15%	**41%**	**21%**	**10%**	**22%**	**24%**	**Variable Weight Fraction**

Figure 9: Weight Breakdown of Battery-Electric and Hydrogen Conversions of a reference Pilatus PC-12, with the Eviation Alice as a purpose-designed aircraft reference. The Range with Maximum Payload and the Variable (Payload + Fuel) Weight fraction is noted in bold under each aircraft description. © *ZeAero%*

What can be seen in the analysis of Figure 9 is the very large proportion of battery mass needed for the Eviation Alice to achieve what is a modest maximum range of 400-440nm. The only variable weight on this aircraft being the payload, which is a small fraction of 15% of the MTOW in this design. In comparison the baseline PC-12, representing a standard Jet Fuel aircraft has a variable weight fraction of 41% consisting of payload and fuel, and also has a respectable range of 1402nm with maximum payload. This variable weight fraction is important as if the operator wishes to use a shorter runway, given the only means to reduce the runway length needed is to reduce weight, the PC-12 operator can do this by reducing the fuel load, whereas the Eviation Alice operator in contrast can only reduce payload. For the Alice this could result in flying an empty aircraft, which is not relevant in most situations.

Also highlighted by Figure 9 is the very limited potential of battery-electric aircraft conversions, as the available carrying potential available for batteries is insufficient. Even if the 9-passenger PC-12 aircraft was reduced to only carry 4-passengers as proposed for the 'Conversion 2' in Figure 9, using the weight instead for more batteries, the range is an extremely limited at 47 nautical miles. This is less than the mandatory safety reserves for a commercial flight, so such a conversion would not be practical for typical airline use.

The two hydrogen conversions of the PC-12 also have a reduced range, the gaseous hydrogen variant like the battery-electric conversion also having less than the mandatory safety reserves. Critically for runway length the flexibility to remove fuel on these hydrogen aircraft is only 1-2% of the overall aircraft maximum weight, which is not significant. This means in practice to operate from short runways the only available action for these converted types is to remove passengers which impacts the economics and ability to perform the mission.

For hydrogen conversions, however the situation can be worse than predicted in Figure 9 as the aircraft conversion developers have to exchange cabin space to install the hydrogen tanks, or may add hydrogen 'drop tanks' on the wings which adds drag. Indeed, the Universal Hydrogen conversion of the Bombardier / De Havilland Q300 installing hydrogen tanks in the fuselage reduces the total seats in the aircraft from 56 to 40(11). This gives an economic penalty as less passengers can be carried whereas most operational costs such as pilots and landing fees are unchanged. For a converted aircraft already having reduced seat count, a further reduction in passengers to enable the aircraft's use on a short runway takes on even more significance.

Making the situation worse for converted aircraft for short runway performance is a tendency of the developers of these aircraft to reduce the total installed power available in an attempt to try to minimise the payload penalty by using smaller electric motors, fuel cells and balance of plant for the aircraft. A reduction in power will increase the take-off run and also affects the required runway length due to engine-out performance.

3.6 TECHNOLOGY TIMESCALES

For planning purposes, the earliest of the zero emissions developments currently on the drawing board is the Eviation Alice, which has already faced a delay from an initially planned 2022 entry into service. With 2024 now proposed as an entry into service this will not be an aircraft type that would be affected by the available runway length at Nelson Airport.

More significant are the Universal Hydrogen(10) Q300 and ATR72 hydrogen-fuel cell conversion types, as these would be types that will be affected by the length of Nelson Airport's runway and could be considered by New Zealand's operators. The earliest date proposed by Universal Hydrogen for its conversion is for an entry into service in 2026. ZeroAvia is another conversion manufacturer proposing a similar timescale with 2026 as a target date. Given current development progress though, it is thought more likely that the first of these types will more likely appear around 2028, and certainly the first hydrogen types should be expected in service by 2030.

Several additional manufactures for hydrogen and battery aircraft are expected to appear in the early 2030's, with the major player Airbus committing to have their first hydrogen fuelled aircraft entering service in 2035(9). This would be the latest point recommended for Nelson Airport to have committed and implemented its runway strategy.

3.7 REFERENCE AIRCRAFT AND GREEN TECHNOLOGY FOR NELSON AIRPORT

In Section 3.5 a degree of understanding of the difficulties of converting aircraft to new energy forms was shared and the large difference in performance between the types of energy storage was highlighted. What remains to understand is how these new energy forms may affect purpose-designed aircraft using these technologies and how all types of aircraft, both conversion types and purpose-designed types might be affected by the runway length at Nelson Airport.

The ATR72 aircraft is used as a representative baseline aircraft as it is a type that is commonly used on the New Zealand network and at Nelson Airport and this aircraft is at the upper end of aircraft size that can use Nelson airport's runway today.

Methodology

Using the proprietary 'ZeAero% Future Projects' aircraft analysis tool, a sizing estimation of new designs for Liquid Hydrogen (both with Fuel Cells and Gas Turbines), Gaseous Hydrogen (with Fuel Cells) and Battery Electric types was made, Figure 10. This ZeAero% aircraft analysis tool uses industry standard analytical methods similar to those that can be found in Raymer(12) to assess the required propulsion sizing, energy storage needs, aerodynamics, aircraft size and weight.

This analysis requires some key future technology assumptions, which were applied as follows:

- It was assumed that Battery technology improves to twice the current state-of-the-art at 440Whr/kg, which corresponds to a projection for battery technology in the 2035 timeframe. A 25% mass loss for battery thermal runaway protection is assumed
- Fuel Cell performance was assumed to be between 45-55% efficient, similar to today's state-of-the-art, depending on the flight phase.
- A 5% improvement in airframe structural weight performance for purpose-designed types was assumed.
- Aerodynamic, wing loading and high lift improvements were incorporated for purpose-designed types, which typically mitigate ~60% of additional runway length requirements that directly applied MTOW increases would otherwise entail.
- The gravimetric index of liquid hydrogen tanks was assumed to be around 0.3, which is state-of-the-art today.
- The gravimetric index of high-pressure gaseous hydrogen tanks was assumed to improve to around 0.08, compared to 0.06 state-of-the-art today.

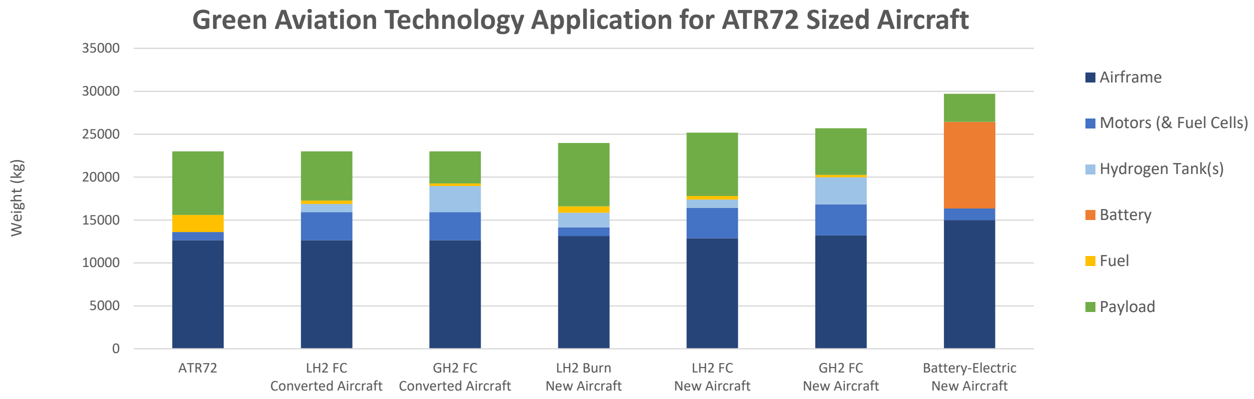
In terms of methodology validation the ZeAero% analysis predicts an increase in MTOW for a purpose-design Liquid Hydrogen Burn type of 4.3% compared to the reference ATR72, whereas the comparable analysis of Mukhopadhaya and Rutherford(13) using the same reference aircraft predicts a 10% increase in MTOW. The slightly less conservative numbers for the ZeAero% prediction are easily explainable due to the ZeAero% analysis assuming improvements in both the structural weight and aerodynamics of the aircraft, whereas Mukhopadhaya and Rutherford(13) did not assume any structural improvements. Secondly the ZeAero% analysis optimised the design for the range with maximum payload, as this most appropriate for the New Zealand network, whereas Mukhopadhaya and Rutherford(13) optimised for a wider set of missions.

The consequence for the following discussion is the ZeAero% numbers are a good reference for discussion, but the exact runway lengths needed by future zero emission types could be longer depending on how the manufacturer optimises their designs.

Results

The output of the analysis is given in Figure 10. This predicts new purpose-design zero emissions types, as well as the performance and weight breakdown of two hydrogen conversions of the baseline ATR72. All the converted aircraft have reduced seat count in proportion to allow for the space and weight of installation of the new fuel tanks.

There is no inclusion of a battery-electric conversion aircraft, as the analytically achievable total range of such a type does not even meet NZ-CAA minimum requirements for such an aircraft. Similarly for the purpose-designed battery-electric type to have a minimum acceptable range, this had to be defined with a reduced cruise speed and reduced diversion minima.



407	**407**	**200**	**407**	**407**	**200**	**100***	**Max Payload Range (nm)**
100%	**100%**	**100%**	**104.3%**	**109.5%**	**111.8%**	**129.2%**	**MTOW Ratio to ATR72**
41%	**27%**	**18%**	**34%**	**31%**	**22%**	**11%**	**Payload Fraction**
68	**52**	**40**	**68**	**68**	**50**	**30**	**Max No. Passengers**

Figure 10: Weight Breakdown of Converted and Purpose-Designed Zero Emissions Aircraft against a ATR72 reference aircraft. The variation of Seat count and Range for each reference should be noted, as should the ratio of maximum gross weight for new design aircraft. (*_NOTE for the Battery-Electric aircraft sufficient performance with a common cruise speed and full energy reserves is not possible, so a reduced 180knot cruise and a reduced diversion reserve was applied_). © ZeAero%

Key factors to note from this analysis that affect economics and infrastructure needs:

1. The seat count is reduced for all conversion aircraft.
2. The Payload fraction (the weight available to be varied, which can be passengers, cargo or fuel) of both converted and purpose-designed zero emissions types is substantially reduced compared to the Jet Fuel powered ATR72 baseline.
3. To match the seat count to enable similar economics (if technically possible) the new aircraft types have a significantly heavier MTOW.
4. Both the gaseous hydrogen and battery-electric purpose-designed aircraft nevertheless cannot however match the baseline ATR72 seat count or range.
5. As stated in the description of Figure 10, to achieve a minimum useful range the battery-electric type has both a lower cruise speed (180knots vs 270knots) and reduced diversion safety margin (100nm only), due to the specific energy limitations of batteries.
6. The hydrogen burn (gas turbine) aircraft, may look like the most attractive variation from a MTOW weight point of view, but has the worst hydrogen consumption of all the analysed types. It is also not a truly zero emissions type, as it will produce NO_X in operation.

Key Points

- The most likely technologies for zero emissions aircraft are battery-electric and hydrogen with fuel cells and gas turbines. SAF will have a role, but is not a true zero emissions solution.
- The significant limitations of near-term battery-electric technology means it is unlikely to be used for larger airline aircraft types before the 2050's. Hydrogen aircraft types appear more promising.
- All technologies for purpose-designed zero emissions types will result in aircraft that are heavier than jet fuelled types affecting runway performance.
- Converted zero emissions aircraft will have reduced passenger count and will have a lower payload fraction affecting runway performance.

4. ZERO EMISSIONS AIRCRAFT RUNWAY NEEDS

Future Zero Emission aircraft types must consider the same physical limitations for runway requirements that legacy aircraft have, whether this is the aerodynamics driving the aircraft performance or the environmental (weather) conditions. However, these new zero emissions types also have to take into account a different set of aircraft and propulsion system characteristics, and these factors result in converted and purpose-designed aircraft types being affected somewhat differently by runway length limitations.

4.1 GENERAL RUNWAY NEEDS

For any aircraft type, to determine the minimum required safe length of a runway several factors must be considered. These include the airport elevation, runway slope, air temperature, wind velocity, aircraft weight, the high lift settings (the flaps and slats on the wings), the minimum airspeed required for control of the aircraft if one engine fails, brake degradation and the runway surface condition (dry or wet). A good summary of runway performance drivers is given in the FAA's Airplane Flying Handbook(14).

Two representative aircraft types for Nelson Airport (NSN), that are commonly used on the New Zealand network and internationally, their size and their runway requirements at ideal conditions at Sea Level and 15°C are given in Figure 11. Also noted in Figure 11 are the total 2019 aircraft movements into Nelson and the frequency of limitations being reached for these types on sectors between Nelson and Auckland (AKL), a key route. It is of note from this figure that there is very little margin for the ATR72 with the current 1347m runway at Nelson Airport, even in ideal weather and runway conditions, and it is of note that even the smaller Q300 aircraft does not have such a large margin to be immune from experiencing limitations as a consequence of the runway length in more extreme weather conditions. This report will use the ATR72 as a reference aircraft type, as it represents 30% of large aircraft movements for Nelson Airport and is the category of aircraft most likely to be affected by runway limitations.

Aircraft	Seats	MTOW	Take-Off at MTOW ISA SL	Landing at MLW ISA SL	NSN 2019 Movements	Times AKL-NSN* Payload Limited	Times AKL-NSN* Pax Offloaded
ATR72	68	23,000 kg	1,315 m	915 m	6870	56%	2.6%
Q300	50	19,505 kg	1,180 m	1,140m	15810	67%	0.4%

Figure 11: Manufacturer's Runway Requirements for common representative aircraft types at Sea Level, Dry Runway and Standard Atmosphere Conditions. *NOTE: Data is collated for both AKL-NSN and NSN-AKL sectors only. *Sources: ATR, De Havilland Canada, Nelson Airport, Air New Zealand.*

Many of the preceding runway factors listed such as the elevation and slope of the runway are clearly fixed, but there are variable operational conditions that can negatively affect runway length requirements for an aircraft. With reference to the ATR72 these include:

- Increase in air temperature (affecting pressure density altitude) – this reduces the wing lift at a set velocity and (usually) also reduces the available engine power. Both effects increase the required take-off length. An increase in air temperature also decreases the effectiveness of the brakes increasing the runway length required. *(according to the ATR72 FCOM an increase in air temperature from 15°C to only 25°C would require a 64m increase in needed runway length for the ATR72, or alternatively a 540kg reduction in payload to utilise the same runway length(15))*
- Wet runway – this increases the rolling friction coefficient, which increases the required take-off length. It also decreases the braking coefficient, increasing the required landing length. *(according to the ATR72 FCOM a minimum 140m increase in required runway length is necessary wet conditions for the ATR72, or an equivalent reduction in payload (15))*

- Wind direction – a tail wind (with the prevailing wind coming from behind the aircraft) will increase the required take-off and landing ground speed and therefore increase the required runway length in both phases. Normally this effect would be addressed by changing the take-off or landing direction for the runway, but there can be situations where this is not possible, for example due to noise abatement reasons, off-set runway thresholds or obstacles at one end of the runway. *(according to the ATR72 FCOM a tailwind up to 10 knots requires a 400m increase in runway length for the ATR72 (15))*

All the above factors would increase the required runway length requirements above those stated in Figure 11, which represents the ideal conditions for the noted aircraft types. Each of the examples above, which represent common occurrence weather events, would cause an exceedance for the ATR72 with the current available Nelson Airport runway length, and thus would necessitate some form of payload reduction below the MTOW for the ATR72 to operate from Nelson Airport. Indeed, Figure 11 highlights that limitations reached the point where on 2.6% of ATR72 missions between Nelson and Auckland they required passengers to be off-loaded.

Aircraft Manufacturer's Toolkit

At the design stage the aircraft manufacturer can improve (shorten) the runway requirements for an aircraft design, normally by increasing wing area and/or adding more complex high lift systems, such as slats and flaps, to the aircraft. In the ZeAero% analysis for the purpose-designed zero emissions aircraft types some benefits from these design changes were assumed.

Such design actions however typically both degrade the overall aircraft efficiency in cruise due to the consequences of increased wing area and increased weight, and they also increase the aircraft costs. These effects are undesirable and ideally the designer will avoid them unless there is a strong business case to justify the inclusion of these changes into the design. Most manufacturers have to balance the absorption of more extreme (short) runway requirements into the design, which will penalise every aircraft operator when they are included, versus the impact such design changes have on aircraft attractiveness for the majority of the market. Consequentially often the manufacturer makes the choice not to design for the full payload on the shortest runways, which will impact airports like Nelson Airport more than other airports.

Aircraft Operator's Toolkit

After the aircraft is designed and delivered, there remain some limited actions left to the aircraft operator to mitigate the effects of elevated airports, short runways, high air temperatures, wet runway conditions and an unfavourable wind direction. This is primarily the reduction of the weight of the aircraft, by either reducing the fuel load (if possible) or reducing payload (removing Passengers or Cargo). Clearly removing revenue payload will affect the economics of the flight.

A real-life example of the above effects would be the operation of the ATR72 aircraft of Figure 11 at Nelson Airport, where the aircraft is only capable to take off from the runway with full load in ideal conditions at 15°C. If the summer air temperature was 25°C, or the runway was wet, neither of which are unlikely occurrences, then the only option to stay within the certified safe limits of the aircraft would be to reduce the aircraft weight by off-loading fuel, cargo or passengers. For a Jet Fuelled aircraft on a short route, then off-loading fuel may be possible without impacting the economics, but this action does reduce the safety margins for weather diversions. However, if the flight is a longer mission and the mandatory safety margins for bad weather are reached it may instead require the removal of revenue payload (passengers or cargo). Indeed, the worst average sector payload reduction for the ATR72 operating into Nelson was reported as 455kg, which is significant, representing the requirement to remove 4 paying passengers potentially. This (A) creates uncertainty for the service as already booked passengers or planned cargo movements may need to be removed due to the weather-runway combination and this often will not be known until the time of the flight, and it creates (B) an economic impact, as the operator may be forced to systematically limit the ticket sales for the service to avoid undesirable customer-upsetting late off-loading, or the operator will have to make financial allowances to pay periodic compensation to removed passengers, increasing the service costs for all users.

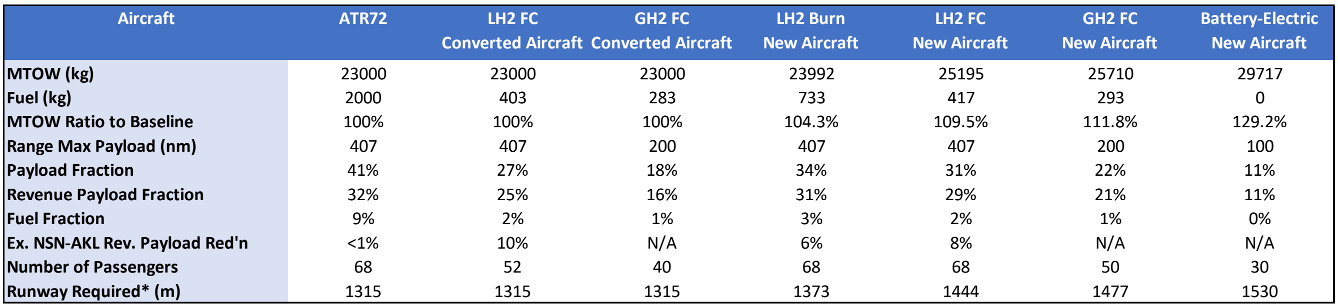
The New Zealand airline network is particularly vulnerable to the effects of undesirable off-loading as the standard per passenger weight (passenger + luggage + onboard amenities) of 110kg means the aircraft are usually operating closer to their maximum weights than in other countries. The value of 110kg is significantly above the typical aircraft manufacturer's assumed 95kg per passenger weight.

4.2 GREEN AIRCRAFT STANDARD CONDITIONS RUNWAY NEEDS

In Section 4.1 the general runway restrictions that legacy aircraft types have has been discussed, and we have seen that the reference ATR72 aircraft even today will frequently face operating restrictions in using the Nelson Airport runway for common occurrence weather variations.

As explained in Section 3.6, the MTOW of purpose-designed zero emissions aircraft types will be higher than a comparable Jet Fuelled aircraft. Some purpose-designed zero emissions aircraft types, such as battery-electric aircraft will also have a reduced passenger count, lower range and slower cruising speed. Converted zero emissions aircraft types will have the same MTOW as the original pre-conversion aircraft but will have a reduced passenger count to allow for the installation of the new fuel and propulsion systems. All zero emissions aircraft types, whether they are purpose-designed or aircraft conversions will have a significant reduction in payload fraction, which is highly significant for runway operations.

Taking the different aircraft variants analysed in Section 3.6 the consequential runway length needs at Sea Level for Standard Atmospheric conditions with an air temperature of 15°C is given in Figure 12, along with other key parameters.



Aircraft	ATR72	LH2 FC Converted Aircraft	GH2 FC Converted Aircraft	LH2 Burn New Aircraft	LH2 FC New Aircraft	GH2 FC New Aircraft	Battery-Electric New Aircraft
MTOW (kg)	23000	23000	23000	23992	25195	25710	29717
Fuel (kg)	2000	403	283	733	417	293	0
MTOW Ratio to Baseline	100%	100%	100%	104.3%	109.5%	111.8%	129.2%
Range Max Payload (nm)	407	407	200	407	407	200	100
Payload Fraction	41%	27%	18%	34%	31%	22%	11%
Revenue Payload Fraction	32%	25%	16%	31%	29%	21%	11%
Fuel Fraction	9%	2%	1%	3%	2%	1%	0%
Ex. NSN-AKL Rev. Payload Red'n	<1%	10%	N/A	6%	8%	N/A	N/A
Number of Passengers	68	52	40	68	68	50	30
Runway Required* (m)	1315	1315	1315	1373	1444	1477	1530

Figure 12: Runway Requirements, Payload fractions and key parameters for different Zero Emission Aircraft types at Sea Level, with Dry Runway and Standard Atmosphere Conditions, versus an ATR72 reference. © *ZeAero$^{\%}$*

Several key points can be read from this analysis:

- The converted zero emissions aircraft types would be able to use the current Nelson Airport runway, but will have reduced available seating, and critically for everyday operations have less payload flexibility (lower fraction) for runway and weather limitations (see Section 4.4)
- None of the 'purpose-designed' zero emissions aircraft would be able to operate from the current Nelson Airport runway length with a normal payload. The LH2 types might be able to use the current runway, but only if they flew with empty seats to reduce weight giving penalised economics (see Section 4.3).
- Large Battery-Electric aircraft types are unlikely to be able to use the current Nelson Airport runway with any meaningful payload, as they have the greatest runway requirement and the least payload flexibility.

It can be seen from the analysed results that the current runway length at Nelson Airport will not be sufficient to operate most of the 'purpose-designed' zero emissions aircraft to match the mainline airline services the airport has today. Consequently, without a runway extension the services to Nelson would have to be 'downgauged' to smaller aircraft types if the desire was to operate only zero emissions aircraft types. The alternatives would be to either request the airlines to have specialised variant aircraft for Nelson Airport (which will be expensive) or to fly with a non-optimal payload (likely to be unreliable and with higher ticket pricing required) for the short runway, or simply to continue to use legacy jet fuel aircraft types that cause pollution in flight whilst legislation still allows this.

4.3 NEW DESIGN GREEN AIRCRAFT RUNWAY OPERABILITY

Figure 12 highlights that purpose-designed zero emissions aircraft types will have a much-reduced payload flexibility compared to legacy types, mainly due to the fuel storage and propulsion system taking up a higher fraction of the fixed weight of the aircraft, but also as a consequence of the lower mass of fuel required with hydrogen and zero mass being altered for batteries.

Battery-Electric Types

A battery-electric aircraft type is the most extreme type in the zero emissions aircraft population, as there is no fuel mass to speak of. Consequentially this type of aircraft gains no benefit from reducing the carried energy. This means if the aircraft operator wishes to use a shorter runway, or environmental conditions require a reduction in take-off weight from a runway, the only option for the operator is to remove passengers or other revenue payload. Further, as the level of weight reduction needed to restore runway performance is proportional to the maximum take-off weight, and this technology type has the highest overall starting weight due to the limitations of battery technology, the weight reduction is doubly penalising.

To give a very simplified understanding of the type of restrictions this technology could require is to assume a 3% reduction of MTOW was required to use the runway. For the Battery-Electric type in Figure 12 this would represent a massive 27% of the potential revenue payload having to be off-loaded, representing a large potential financial loss for the aircraft operator. In contrast for the ATR72 on a typical mission, using the key Nelson-to-Auckland flight for reference, with the ability to off-load fuel the ATR72 could lose less than 1% of its revenue payload for a 3% MTOW reduction. Further the ATR72 baseline has a better runway performance to start with and is less likely to require MTOW reductions as frequently.

Consequentially it must be recognised that battery-electric types will be very inflexible for operations from short runways, particularly those where penalising environmental conditions are frequently encountered.

Gaseous Hydrogen Types

It can be seen in Figure 12 that gaseous hydrogen types are the most performance restrictive type after battery-electric types. Gaseous hydrogen aircraft have lower range and lower seat count for an overall heavier aircraft take-off weight than both the liquid hydrogen types and the baseline ATR72. For this reason, the author believes such technology will most likely only appear on conversion aircraft types for expediency and will be less common or potentially never built as a new purpose-design due to these performance disadvantages.

If such a type was built and available for use at Nelson Airport, it is noteworthy that the fuel weight fraction is only 1% of the maximum take-off weight and the type is also penalised by the short-range capabilities of the technology (it does not have the range for the Nelson-to-Auckland sector). Therefore, any environmental conditions requiring a take-off weight reduction will in most cases result in an off-loading of payload penalising the economics of the flight.

Taking the same example of a 3% reduction in MTOW to meet runway length limitations, this would represent a large 14% reduction in revenue payload. As this aircraft type also has the second worst runway performance to begin with, it makes the likelihood of such occurrences being high and will certainly is a reason why this technology type will probably be unattractive longer-term.

Liquid Hydrogen Types

These types are the only ‘purpose-designed’ types that can match the ATR72 reference aircraft for range with maximum payload and for passenger count. This makes this technology the most likely zero emissions replacement aircraft to come to market in the 2030’s as the economics will be better than other zero emissions technical options and the technology will also offer a like-for-like aircraft replacement that will fit into airline networks more seamlessly. (*Noting however that Hydrogen Burn is not a true zero emissions technology even if it eliminates* CO_2*, as* NO_X *will still be emitted*).

Still compared to the reference ATR72 aircraft these types may not only require a greater standard runway length in ideal conditions, but they will have less flexibility for weather effects. Even if the liquid hydrogen types will be substantially better than gaseous hydrogen and battery-electric types, both the Hydrogen Burn at 3% and Fuel Cell aircraft at 2% have low amounts of fuel mass to off-load if required due to runway limits. Assuming once more that a 3% MTOW reduction for runway length was required for a mission from Nelson to Auckland, it would require a reduction of 6% and 8% of revenue payload respectively for hydrogen burn and hydrogen fuel cell types.

If however Nelson Airport’s runway was extended to 1510m as proposed, this would accommodate both liquid hydrogen types for operations in standard environmental conditions. Additionally, the 1510m length gives enough runway margin over the basic runway requirement for common occurrence weather events such as elevated summer day air temperatures, that the frequency of payload reductions will not be severe.

4.4 CONVERTED GREEN AIRCRAFT RUNWAY OPERABILITY

Figure 12 could superficially be read that no additional considerations for converted aircraft operations from Nelson Airport compared to the ATR72 were needed, as the standard conditions needs match the ATR72. However, in real world terms this is not case.

Firstly, for the operators of a converted type the size of the ATR72 the converted aircraft will have a reduced passenger capacity that is even less than the Q300 aircraft, a category below the ATR72 reference. Therefore, these converted types will not be a like-for-like replacement and will require greater staffing and capital assets to move the same number of passengers than the baseline aircraft. In the case of the gaseous hydrogen conversion the maximum payload range is additionally penalised thereby making airline network integration a further difficulty.

More importantly from an operability point of view, these converted aircraft have a significantly greater payload impact compared to the baseline if the environmental conditions and runway length require take-off weight reductions. Taking again the same assumed 3% reduction in MTOW for runway limitations, the gaseous hydrogen aircraft conversion, as it also has a shorter range, would for most missions only have the option to remove revenue payload, requiring a significant 18% of payload to be removed. This is in contrast to the reference ATR72, which for the Nelson-to-Auckland mission would typically require less than 1% payload reduction.

The liquid hydrogen aircraft conversion is somewhat better, as it has a better range and payload fraction. However, again comparing it to the ATR72 reference for the Nelson-to-Auckland mission with a 3% MTOW reduction, the converted aircraft still requires a penalising 10% payload reduction versus 1% for the reference.

The consequences of this are significant for operations, as periodic 10% reductions in payload for converted zero emissions aircraft types for common occurrence weather events will significantly compromise the predictability and reliability of the service to the point that it may not make economic sense to operate such types into Nelson Airport.

Conversely if Nelson runway was extended to 1510m then the need for MTOW reductions due to the runway can largely be avoided even for the converted aircraft, meaning operations would achieve an acceptable level of predictability and become viable for Nelson Airport.

Key Points

- The ATR72 today is already compromised by the short runway at Nelson Airport for common occurrence weather conditions, such as summer weather or rain.
- New purpose-design zero emissions aircraft types will require longer runways, and minimum runway needs would not be compatible with Nelson Airport without the planned 1510m extension.
- Converted zero emissions aircraft types are penalised more by payload reductions for runway length than the ATR72 baseline and purpose-designed types, and will have lower passenger capacity.
- Nelson Airport's current short runway combined with common weather occurrences may require a frequency and level of payload off-loading for zero emission types that make services to Nelson too unreliable and uneconomic to be viable.

5. IMPLICATIONS FOR MAINTENANCE AND GROUND FACILITIES

Today Nelson Airport has a range of maintenance operations on site, which contributes highly skilled and well-paid employment to the region. Consideration of how the introduction of new types of aircraft technology may affect this should be included in the future airport planning.

Similarly, the introduction of new energy sources for new zero emissions aircraft types will require some thought over the appropriate anticipatory investments to provide refuelling or recharge facilities for these aircraft. With the levels of unknowns still affecting the technology transition there is a risk of over-investment in technologies that do not become mainstream or have a short period of relevance.

Key recommended points to consider are:

- The ability to fly aircraft into Nelson Airport for maintenance using revenue flights to avoid the unnecessary expense and crew logistics of empty positioning only flights.
- The ability to refuel or recharge the aircraft at the airport. Particularly for instances after the completion of maintenance, or a long period of storage, where the aircraft has had to be refuelled as part of the maintenance process.
- Avoidance of premature investment in refuelling or recharging facilities that may have a short period of relevance or not become mainstream.

Ability to Avoid Positioning Only Flights

Referring back to Figure 12 for the comparison of the runway performance of the different zero emissions aircraft types it can be observed that none of the purpose-designed zero emissions types will be compatible with the current Nelson Airport runway for revenue missions. This means the economic costs of additional positioning flights would need to be factored into the decision to place regular maintenance activity on such types at the airport. The large battery-electric types may not be compatible with the current runway length, even without payload.

Converted zero emissions aircraft types would however be able to operate into the current runway with paying payload, albeit with the limitations described in Section 4.4. However, it must be realised that as these converted aircraft types will have constrained economics compared to purpose-designed aircraft, it means that they certainly will only be a stop-gap type until purpose-designed clean-sheet designs are available to replace them. This will probably bring runway limitations for the future aircraft types into play for shorter-term maintenance decision making. Therefore, investment in maintenance infrastructure and upskilling of staff that may only be applicable for these converted aircraft types, which in turn may have to be relocated to an airport with a longer runway for future purpose-design types may influence the decisions on where to perform the maintenance even on these converted types.

If Nelson Airport anticipates this risk with the commitment to extend the runway to protect for purpose-designed zero emissions aircraft types, then it will remove a potential disadvantage for continued maintenance operations from the airport.

Refuelling and Recharging Facilities

Section 3.6 and Figure 10 describes the capabilities and limitations of the various technologies and their application to airline use. This analysis highlights the very limited and restrictive performance of battery-electric types, and it is highly likely as a result that few large battery-electric aircraft will be developed until the 2040's or later. It is probable in the near term the main use for battery-electric aircraft technology will be for training aircraft types, which are restricted to distances close to the airport, such as the Pipistrel Alpha Electro(16), and potentially smaller business and sub-regional types like the 9-passenger Eviation Alice(7). As such it would be prudent not to over-invest in aircraft charging stations at Nelson Airport until the aircraft capabilities are proven and certified, and the demand clearly eventuates.

In an airline context it is much more likely that hydrogen aircraft types will be deployed on the New Zealand network. There is a possibility that this deployment could include gaseous hydrogen types in the near term, using very high-pressure hydrogen gas. Given the short ranges of the aircraft with this type of technology, then gaseous hydrogen refuelling capabilities would be needed at Nelson Airport to enable their operation. However, any investment should anticipate the high risk that this technology is only an interim step towards the deployment of liquid hydrogen fuelled aircraft, and that such an investment may become redundant with time. It would therefore be wise to either limit such investments, or structure the technical solution so that it has the ability to be converted to liquid hydrogen supply in the future.

If the New Zealand airline network introduces purpose designed liquid hydrogen aircraft types, then due to the range potential of these aircraft there is a possibility that the liquid hydrogen refuelling infrastructure could be limited to the main airports of Auckland, Wellington and Christchurch as these aircraft could be designed to tanker sufficient fuel for more than one sector. There would remain a good case for installing a liquid hydrogen refuelling capability at Nelson Airport, for:

a) Fuelling of aircraft which have major maintenance performed at the airport, requiring the defueling of the aircraft.

b) Fuelling of an aircraft that has been stored for a long period of time at the airport resulting in hydrogen boil-off and the need to refuel.

c) Fuelling of an aircraft that has had a weather diversion, to give complete flexibility for selection of its next sector.

Given the high specific energy of liquid hydrogen the amounts of fuel required at Nelson Airport may be small enough that the refuelling capability could simply be provided by an on-call road transport solution from another liquid hydrogen production site. Alternatively, if good access to cheap renewable energy is available, then on-airport production is also a potential good solution to consider.

Key Points

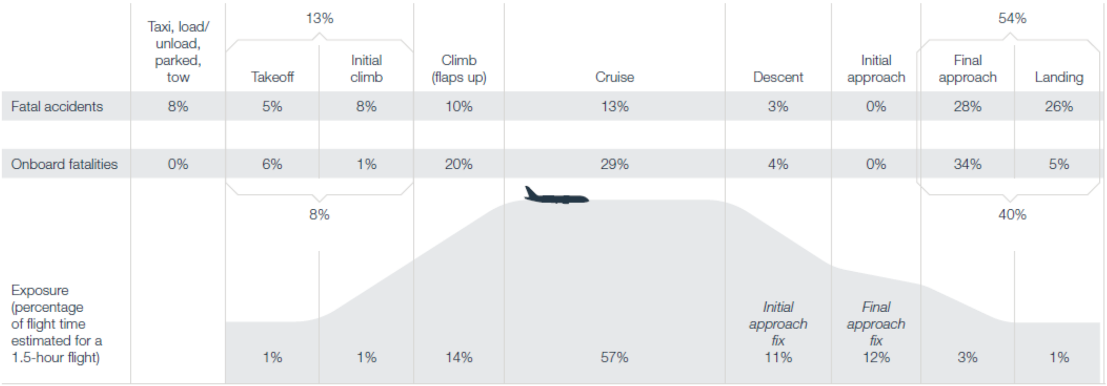
- Not extending the runway at Nelson Airport could prejudice continued maintenance activities at the airport versus the longer term needs of replacement zero emissions types.
- The exact long-term requirements for recharging and refuelling capabilities for future zero emissions types is unclear, and may be over stated or mis-selected, so care in investment choices must be taken.

6. RUNWAY SAFETY CONSIDERATIONS

The discussion in this report thus far has been around the certified minimums for reference aircraft types currently in service and probable certified minimums for the future zero emissions aircraft types. This should not preclude a more general discussion with regards to operational aircraft safety and the place that runway length has in the safety conversation.

The certification basis of any aircraft type, existing or new technology, combines prior industry learning with a theoretical level of safety using a statistical basis with the intent to avoid accidents in most likely cases. These certified limits do not however guarantee no accidents, rather they define a minimum acceptable level of safety and all actors in the industry, whether manufacturer or operator, should always encourage the provision of additional safety margins where it is reasonably possible.

To this end it is notable that 67% of all fatal aircraft accidents occur during the flight phases linked to the runway$^{(16)}$, that is in the take-off and initial climb phases, and the final approach and landing phases, as seen in the accident data that Boeing has collated in Figure 13. Whilst the probabilities of such accidents occurring can be improved by factors such as better training of crews, and enhanced aids and automation within the aircraft, it cannot be denied that the available runway length is an important factor in all these critical flight phases. In Boeing's research runway excursion is the fifth most common cause of fatalities in commercial flights, which is directly influenced by the available runway length. And the influence of runway length cannot be discounted as a contributor for accidents in the initial climb and final approach phases, as any runway length limitations place additional pressure on both the crew and equipment.



Note: Percentages may not sum to 100% because of numerical rounding.

Figure 13: Commercial Jet Aircraft Fatal Accidents by phase of Flight, from 2011 to 2020.
Source: Boeing Statistical Summary of Commercial Jet Airplane Accidents.

For this reason, any move to increase the length of Nelson Airport runway, and introduce Runway End Safety Areas, will positively improve safety margins for the highest risk phases of flight operations to and from Nelson Airport. Whilst the runway extension will be important to enable the introduction of zero emissions aircraft types, the safety consideration alone is a worthy reason for such investment.

Key Points

- Certified minimums are NOT a guarantee of zero accidents and it is always recommended to provide additional margin where it is possible.
- 67% of fatal accidents happen in flight phases where runway length has an influence, so any move to extend the short runway at Nelson Airport are recommended solely for the enhancement in safety.

7. KEY CONCLUSIONS

The following key points can be derived from the discussion in this report regarding Nelson Airport's runway length limitations in relationship to operations of future zero emissions aircraft types and improved safety, and the case for extending the runway to 1510m with RESA.

1. Analysis of the existing large aircraft types using Nelson Airport, particularly the ATR72 which makes up 30% of movements shows that this legacy aircraft type is already negatively impacted by common occurrence weather effects due to the short runway at Nelson Airport.
2. Future purpose-designed zero emissions aircraft types will most likely be higher weight for the same passenger and payload capacity, and most likely will require a runway that is longer than the current runway length at Nelson Airport.
3. Future zero emission aircraft types also have a much-reduced payload fraction and payload flexibility to manage runway limitations compared to legacy Jet Fuel types, as the propulsion and energy storage systems are a higher proportion of fixed weight.
4. This reduced payload flexibility means common weather effects combined with Nelson Airport's short runway length will result in more frequent need to reduce payload and by a larger percentage. This may make the passenger service so unreliable for converted zero emissions types that it may be uneconomic for these aircraft to use Nelson Airport.
5. The economic risk of not extending the runway on the continued relevance of maintenance operations at Nelson Airport should be a consideration, as the current runway length may make it unsuitable for some zero emissions aircraft types and require non-revenue positioning flights for maintenance of these types at the airport.
6. It is recommended that the strategy to provide recharging and refuelling capabilities at the airport be carefully considered, so as to avoid investment in infrastructure that may not become mainstream, but with enough provision to protect existing services at the Airport.
7. For basic safety considerations, given that 67% of fatal accidents occur in flight phases associated with runway length, and because certified performance limits are a minimum safety standard the extension of Nelson Airport runway to give the stakeholders who use the airport additional safety margins is a worthwhile investment.

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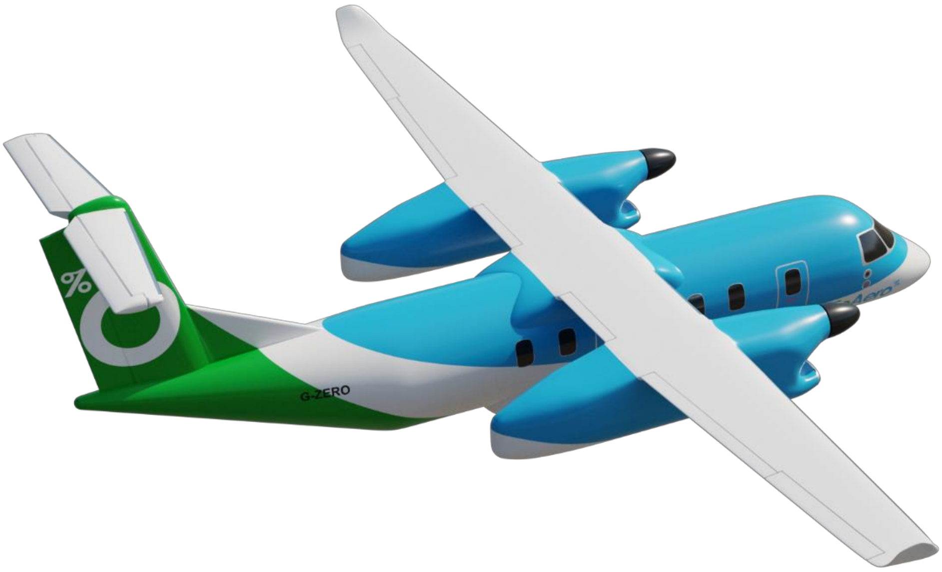

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