Submission on

Emerging Aviation Technologies: National Aviation Policy Issue Paper

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Executive Summary

- The Emerging Aviation Technologies NATIONAL AVIATION POLICY ISSUES PAPER (the Issues Paper) is an important starting point in the national conversation about the future of aviation in Australia,
- Aviation is entering into a period of significant technological disruption. Drones and Electric vertical take-off and landing aircraft (e-VTOL) are only part of an emerging market, but this market is evolving quickly with electrification likely to extend to short haul fixed wing aircraft (e-SH-FW aircraft) by 2030,
- The technological disruption timeframes for electrification of short haul aviation and the scale of the impact are such that the Federal Government should take a high level of interest and be developing an appropriate policy response,
- The scope of the Issues Paper is too narrow and should be extended to consider opportunities for electrification of short haul fixed wing aircraft (medium term ~ 5 to 15 years) and alternative fuel and emerging aircraft (long term ~ 10 to 20 years),
- The on-going rapid development of battery technology will be transformative not just for drones and eVTOL but also fixed wing short haul aircraft. Initially driven by increased energy density of batteries and reduction in battery costs,
- The electrification of the short haul commercial fixed wing aircraft is likely to occur in the short-medium term (10-20 years). The range for electric short haul in this period with sufficient redundancy for commercial operation, is likely to be at least in the 1500km range effectively making regular commercial short haul flights in the 200km to 800km achievable,
- e-SH-FW aircraft will increase the speed of intra-regional travel and if trips are competitively priced will increased the demand for intra-regional travel, and
- There are significant unknown disruptions, technological breakthroughs and impacts that justify the Australian Government widening the scope of the emerging aviation review to consider out to the 2040 technology horizon with specific consideration of potential fundamental technological innovations that will impact on short haul small PAX aviation within the next 10 years (2030).
- An extended emerging aviation review should include:
    - Research to understand the potential impacts on transport infrastructure, urban settlement patterns and regional services with the development of commercial short haul, small PAX aviation service
    - Research to understand the potential impacts on industries such as tourism.
- The Australian government should also consider the development of a national emerging aviation industry development strategy starting with a national review and audit of R&D and industry capability.

Disclaimer

The opinions and views contained within this submission are personal academic opinions and are those solely of the author, Dr Michael Patrick Kane, and do not represent the views of Curtin University or my employer, the Queensland Government.

Technological Context

Aviation has entered a period of disruption with both Covid 19 and increasing concerns with climate change and global emissions radically changing short term and medium term passenger demand. Periods of economic and social disruption often see rapid technological in response as opportunities arise to meet changing market demand and economic scenarios.

Various technological advancements are being made to address need for aviation industry to address GHG emissions performance including:

- Batteries technology and price advancements, particularly with advanced Li Ion, Li Metals, Li Sulphur and Solid State batteries over the next decade
- Supercapacitors
- Light weight high powered electric motors
- Aircraft redesign including high levels of light-weight materials being incorporated into aircraft
- Aircraft redesign including incorporation of batteries into structural elements and distributed propulsion systems
- Electric hybrid aircraft
- Software and avionics
- Zero emission fuels including hydrogen and biofuels

These technological advancements are likely to be realised in commercial aircraft over the next 5 to 20 years with significantly ambitious range of electric and zero emission aircraft R&D underway around the world (Ansell & Karan, Sahoo et al 2020). The timeframe for some changes being incorporated into aircraft will be over the medium-longer term (15 to 20 years) such as zero emission fuels (i.e. hydrogen), mass inclusion of light weight materials, and the incorporation of batteries into the aircraft's structural elements (such as wing) due to the requirements for safety certification often being a multi decade process. Some technological advancements will add to the capital and operational costs of aircraft however some will likely reduce the operational price structure of commercial aviation, notably electrification.

Technology and cost structure advances, notably in electrification and materials are likely to arise from increasing levels of technology performance and commercial scale in both the electric vehicle & space industries. Both these industries are seeing greater technological disruption and advancement in recent years than they have seen for many decades. In this respect aviation technological advances will be supported from these associated industries.

The increasing electrification land vehicle transport and the advances in battery energy density, longevity, and price has created opportunities for the electrification of short haul aviation. For e-VTOL and the e-SH-FW aircraft this opportunity is within the short to medium term (5-15 years). The range for electric short haul in this period is likely to reach up to 1000km range effectively making regular commercial short haul flights in the 200km to 800km highly achievable within 10-20 years. This will be initially driven by increased energy density of batteries, advances in electric motors and reduction in battery costs. Subsequent larger two aisle aircraft redesign incorporating high levels of light-weight materials and structural inclusion of batteries will further add to the opportunity in the medium to longer term (15 years plus).

The commercial application of short haul aircraft electrification will be shared between e-VTOL and e-SH-FW aircraft. Both e-VTOL and e-SH-FW aircraft will have advantages and distinct areas of performance. E-VTOL's major advantage is in manoeuvrability and flexibility in terms of take off and landing, while its disadvantage is in energy efficiency and carrying capacity (Stahl et al 2018, Dündar et al 2020). E-VTOLs' advantage will therefore support their use in built up areas (similar though superior to the way helicopters are used in built up environments).

E-VTOLs will provide short haul services in respect to very low PAX flights (<10) over distances of 100-200km, though most likely commercially over 50km as to enable multiple constant flights (without recharging/battery swapping). E-SH-FW aircraft will likely undertake low to medium passenger movement (50-70 PAX) over distances up to 1000km (500 nm). It is also plausible that we will see cross over (fixed wing VTOL) aircraft developed which improve the range of VTOL aircraft (see unmanned fixed wing VTOL aircraft development in Stahl et al 2018)

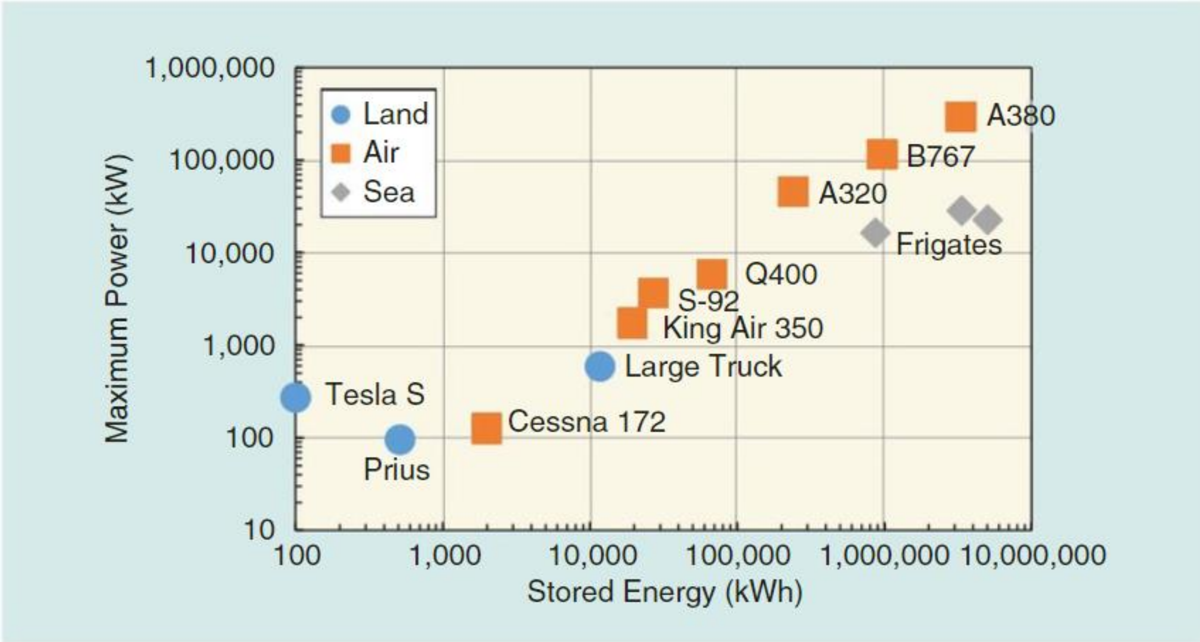
The assessment of the opportunities for commercial short haul electric aircraft is based on the technological review of electrification of aviation by Sahoo, Zhao & Kyprianidis (2020) and Barzkar & Ghassemi (2020). Sahoo et al (2020) predict that in 15–20 years there would *"be adequate market pull for electrical aircraft to fly in the short and medium range aircraft applications."* Barzkar & Ghassemi (2020) believe that it is not *''if'' but rather ''when''* narrow body, single aisle medium haul aircraft (i.e. Boeing 737 type aircraft) will be operating commercially, i.e. 3600 nm (nautical miles; almost 6700km), being *"possible within the next 20 years."*

The effective challenge for electrification of aircraft increases substantially with increased in scale and weight of the aircraft (Ansell & Haran 2020, Sahoo et al 2020). Ansell & Haran (2020) foresee short-medium haul flight with passengers (PAX) numbers of 48-68 flighting 600 nm (1111km) as the likely target initially for electric hybrid aircraft. Sahoo et al (2020) see all electric as being possible on short haul routes (sub 1,000km) and low PAX (sub 80).

The commercial scale of this short haul electric aviation opportunity is high with Sahoo et al (2000) noting that, based on the existing cost structures, that the US regional segment fleet operation in the less than 500 nm range segment accounts for about 91% of the global single-day operations. Effectively the "*…demand growth in the less than 600 nm range and the availability of regional/commuter airports makes suitable market opportunity for electric aircraft operation."* Ansell & Haran (2020) have also noted the commercial potential of electrification of short haul flight noting the significant populations in Europe, USA and Asia who are within short to lower medium haul flight ranges (sub 1500km). The other benefit of the electrification of short haul aviation in addition to reducing emissions, is the operational cost reductions. Sahoo et al (2020) noting the opportunity that with an "*introduction of an innovative pricing scheme and cutting-edge technology there could be potential reduction in the maintenance and energy cost, which would reduce the direct operating costs in this segment."*

The key driver for electrification of aviation is the specific energy / energy density for batteries (Ansell & Haran 2020, Sahoo et al 2020). The useful specific energy of jet fuel (after losses) is around 4,500 Wh/kg whereas Li Ion batteries are presently at 250Wh/kg - 260 Wh/kg (Ansell & Haran 2020, Lu et al 2020) though in application within aircraft it is likely to be lower (Ansell & Haran 2020). Table 1 sets out the power and energy requirements of aircraft types and other transport modes.

Table 1. Power and energy requirements of various transportation platforms



Source: Ansell & Haran 2020

Increasingly year by year larger scale electric trucks and buses are being brought to market as large scale transport reaps the benefit of electrification.

The size of the commercial opportunity for short haul electric aviation will be a significant reason for the continued advancement in battery technology. Table 2 sets out the projections as to cell level energy density for the enabling of short haul aviation in terms of passenger capacity and range.

Table 2. Payload/range projection for fully/hybrid electric aircraft

Battery SE-Cell Level in Wh/kg	Hybrid Electric (Segment/Range)	Fully Electric (Segment/Range)
250	2–3 PAX, 200 nm	6–10 PAX, 300–600 nm
400	19 PAX, 500 nm 30 PAX, 400 nm	19 PAX, 400 nm 50–70 PAX, 300 nm
500	50–70 PAX, 500 nm	30 PAX, 500 nm 50–70 PAX, 400 nm

Source: Sahoo, Zhao and Kyprianidis (2020)

Notably the (possibly conservative) academic technological review by Sahoo et al (2020) is looking backwards to reported technological knowns. For example, the Sahoo et al (2020) review is of the cell level Wh/kg and it was notable in the recent Tesla battery day presentation of the innovative intent to reduce battery pack materials and weight, hence overall reducing the weight of the battery system overall. With the considerable commercial application of new battery cell technology, the lack of full and open disclosure of the advances in battery technology is likely to mean it will be difficult to predict battery advancements beyond 5 years with any degree of accuracy. We are likely to see periods of little apparent progress followed by a series of announced technological breakthroughs.

Advanced commercial Li Ion batteries are, based on the recent Tesla Battery Day, likely by 2023 to exceed the present rate of energy densities of 250/260 Wh/kg. However newer battery chemistries and technologies are likely to be the key transformative driver of commercial electric short-medium haul aviation. Solid-state batteries such as rechargeable zinc alkaline, Li-metal, and Li-S are more likely to be the means of electrifying heavier mobility applications than Li Ion. Wu et al (2020) addresses the limitations with existing Li-ion battery chemistries noting that to satisfy the growing market demands for denser, more affordable and lighter batteries, new battery materials and chemistries must be developed. For example, Li–O2 and more so Li–S offers high energy densities, yet both have substantial problems. Li–S batteries show the most potential for commercialisation. This challenge is seeing considerable global investment on research into several new energy storage chemistries. Wu et al (2020) express confidence that promising chemistries *'will more likely realize highly-needed smaller, lighter, cheaper, greener and safer batteries in the next 5–10 years*.' Next-generation rechargeable Li and Li-ion battery technologies needing at least 5 more years though other batteries chemistries may need more than a decade of fundamental research to mature for wide industry adoption.

Bloch et al (2019) similarly contends that as early as 2025, and no later than 2030, long-duration energy storage non-Li-ion battery technologies will have made significant commercialisation steps through demonstration to early-stage deployments in short-duration aviation. Weber et al (2019) associated with Tesla Canada R&D report strong energy density potential of Li-Metal (40%-50% increase). The limitation with Li-Metal as developed is with the life cycle which is insufficient at this stage for commercial use. If liquid electrolytes can be used to create safe, long-life Li-metal cells, then existing manufacturing processes could be applied for rapidly commercialisation of high-energy-density cells.

Li-S batteries have, while demonstrating high energy density (expected up to 600Wh/kg and higher), at this stage of their development poor life cycles (Cano et al 2018). If life cycle can be addressed, then this would be a significant breakthrough for electric aviation.

Table 2 sets out the reviewed predictions as to the different energy density potential of Li Ion and Li-S battery chemistries.

Table 3 Performance projection of Li Ion and Li-S battery chemistries

Technology	Specific Energy (Wh/Kg)		Specific Power (kW/kg)		Cycle Life (Numbers)	
	SOA	Future Projection	SOA	Future Projection	SOA	Future Projection
Li–Ion	80–200 [105]	400 [1], 450 [2] [105], 300 [3] [227], 250 [4] [8]	0.3		>300	400–450
Li–S	250–300 [105], 160–350 [19,235]	500–650 [1], 800–950 [2] [105], 600–700 [3] [227], 500–1250 [4] [8]		1 [233]		1000 [230]

Source: Sahoo, Zhao and Kyprianidis (2020)

Ansell & Haran (2020) among others are sceptical on the early development of 1000 Wh/kg batteries within 10-20 years and it is likely that electric aviation in this period will be limited to 500-600 Wh/kg batteries and short haul (sub 1,000km) and low PAX (sub 80).

With energy density levels of 500 Wh/kg required to enable short haul commercial flight Li Metals/Li Sulfur and solid state batteries are predicted to have significant energy density potential beyond 500Wh/kg (Sahoo et al 2020, Wu et al 2020). Advanced Li Ion with other battery pack innovation may also result in effective 500Wh/kg performance. Under either scenario short to medium haul electric aviation will be enabled.

Electrification adds a great amount of complexity to aircraft and there are significant challenges for electric aircraft, notably with longer range and high altitude flying (Barzkas & Ghassemi 2020, Borghei & Ghassemi 2020). The other key driver is the power requirement (intensity of energy required) from motors, inverters, energy management systems, power transmission and circuit protection will also require a range of innovations (i.e. high voltage systems) to enable electrification of medium-long haul flight (Ansell & Haran 2020, Barzkar & Ghassemi (2020).

Fossil fuel burn is largely (57%) with larger two aisle aircraft (Ansell & Haran 2020) and this will a key driver of continued electric and zero emission fuel innovation in aviation. Beyond electrification there are likely advances in zero/low emission liquid fuels (i.e. hydrogen/syn/bio fuels) aircraft redesign (i.e. light-weight materials, battery and super capacitors structural incorporation) and hybridisation (i.e electric-fuel aircraft) to enable zero emission medium-longer haul aircraft. Electric hybrid aircraft has the potential to parallel the success of hybrid light vehicles as a transitionary technology – delivering significant reduction in fuel consumption, maintaining most of the features of standard vehicle/aircraft. With new aircraft design and technology incorporation in larger new commercial aircraft requiring significant time periods for safety certification 2040+ is the likely timeframe for more radical change beyond incorporation of batteries within short haul aircraft.

It is highly plausible that in the 2025-2040 period short haul electric aircraft will have a significant price and emissions advantage over longer haul flight. This could see a global shift in patterns of air travel with more two-flight hub-spoke movements (with one or both movements being electric). Alternatively, people may increasingly elect to visit shorter trip destinations rather than take longer flight trips. For Australia electric aviation is likely to see more regional city airports providing national hub and spoke services for their surrounding regions. This may be an opportunity of significantly reducing flight costs in regional Australia. Increased demand for short haul flights is also likely to see increased demand for electric aircraft assisting in reducing the capital costs of new aircraft and high usage rates reducing operational costs. This provides opportunities and challenges for Australia both in preparation for and the adoption of short haul electric aircraft.

Technology and economic development opportunities

As the Issues Paper states (p.3) the applications of new aviation technology is where the real potential for significant economic and social benefits exist. The growth in new emerging aviation technologies will create a range of economic opportunities both within the aviation industry and beyond. The impacts are beyond the advent of drones and e-VTOLs. The likely industry opportunities are:

- Electric aviation commercial short haul intra and inter regional services increasing commuting at distances up to 500km, particularly servicing people working a mix of in office and at home
- Short trip tourism for both domestic and international to locations with electric aircraft reach of major cities,
- Goods delivery to consumer markets and wholesale delivery i.e. high value perishable agricultural goods moving to market and to transport nodes
- Electrification aviation and ground technological development opportunities (electric fixed wing aircraft/VTOLs, charging infrastructure,)
- Electrification of industry more generally and cross-over of technologies electric watercraft, electric boats/ferries, charging infrastructure, battery services)

As stated previously electrification adds high levels of complexity to aircraft and there will be significant challenges in the development of electric aircraft and associated systems required for successful commercialisation. Avionics, light-weight materials and structural integration of battery systems, electric aircraft pilot training, zero emission fuels (hydrogen, biofuels), and power systems industry opportunities (motors, inverters, energy management systems, power transmission, high voltage systems and circuit protections) will all require a range of innovations to enable commercial electrification of short, medium-long haul flight.

Technology and industry development opportunities with electrification of aircraft will be a multi-billion opportunity. At this stage in Australia there is no active government consideration of the Australian electric aviation industry development opportunities. As aviation industry globally starts to embark on a radical overhaul Australia is presently sitting on the sidelines defaulting to be a technology taker rather than an industry and technology developer.

Urban and Regional Opportunities

One likely impact of short haul electric aviation will be impact on Australian cities and urban settlement. It is realistic and plausible to assume that low cost short haul (<500km), small PAX (30-80) commercial services in Australia by 2030, and highly likely by 2040. Services distances of 300km provide coverage of the surrounding regions of Australian cities and key satellite cities (i.e. Sydney and Canberra). This could significantly influence the future settlement patterns of Australia's major capital and regional cities (and their surrounding regions).

Understanding trends of transport and ICT impacting Australia's settlement pattern is important, particularly as the Australian and State governments considers investing considerable public monies in major infrastructure such as high speed rail, Badgerys Creek Airport and urban rail connections for Melbourne and Badgerys Creek airports.

The shape of cities and settlement patterns are determined largely by transport technologies and cost. Australia's settlement patterns are very distinct - larger and growing primary capital cities and key regional cities. There has been continued growth in the size of Australia's major cities and an increased share of the national population despite the increasing technological advancements in transport and ICT and reducing costs over the course of the 20th and 21st centuries.

Increased population attraction to capital and major regional cities is likely to continue but with major cities transforming into city regions encompassing satellite cities and towns. This is the experience with large cities globally. For large cities their productivity and competitive advantage is, to a large degree, driven by their knowledge and service industry labour market scale at the urban core, including their capacity to pull labour into the urban core from suburban areas of metropolitan areas (Moreno-Monroy et al 2020). Increasing populations are decentralizing into commuting suburbs and satellite cities and towns (Moreno-Monroy et al 2020) while knowledge intense high productivity and higher paid jobs are not. This means there is an inherent need for increased transport in growing cities.

For this increase in spatial size of cities to be managed *transport speed* is required. Motor vehicles in congested commutes do not provide for speed or spatial efficiency while fast rail is effective it is high cost and likely only to be justified in a limited number of high volume urban corridors. Electric short haul aviation is a strong possibility to meet *some of the demand* for increased intra-regional and inter-regional transport.

What is also likely to drive demand for long distance commuting is increased levels of part office part working from home. While Covid-19 has highlighted the opportunities for remote working using digital, Kane (2016) has argued that digital does not replace 'place' (cities/offices) but it does extend it. Effectively places creates opportunities for trust (which is an essential precursor for knowledge development) and for other labour market agglomeration benefits. ICT however allows these benefits to be extended over distance, supporting a mix of remote and placed based work. This is an essential element to understanding that cities globally are continuing to increase in size and scale.

This growth in larger cities globally is seeing both increased population density and increased spatial spread. This creates a tension between compactness/density (as benefiting productivity/wages) and spatial spread with lesser density (benefiting residential amenity/lifestyle). Effectively cities are continued to benefit from increased urban density at the core but also increased spatial spread, particularly where there is amenity in near regional locations.

Impact of low cost short haul (<300km), small PAX (30-80) commercial services by 2030 would likely encourage longer commuting and digital remote working enabling people to do 2/5 or 3/5 days while choosing where they want to live within reasonable distance of major cities. The opportunity cost savings with electric short haul aviation could also be significant in that it is also relatively low cost (in that there is little additional infrastructure required) compared to long distance rail lines servicing high speed services. Where high speed rail is justified electric short haul aircraft nodal links could provide an extended high speed rail catchment area.

Reduced noise from electric aircraft (Ansell& Haran 2020) and air pollution could possibly see curfews removed and complaints about extended use of both smaller urban and major city airports reduced. Noise and air pollution reductions will enable greater flight numbers/hours of operation for major *AND* smaller urban and regional airports. The additional competition is likely to benefit aviation cost reductions. These localised environmental benefits in addition to greater demand for short haul flights could also see greater demand for other second and third tier urban airports.

Regional and secondary/tertiary urban airport will also likely benefit with increased hub and spoke airports providing for short haul connecting flights. Hub and spoke movements are also likely to increase in the urban context with e-VTOLs services potentially connecting city and urban airports to city centres, key suburban and regional rail stations, and suburban shopping centre transport hubs. While e-VTOLs may be difficult to justify over residential areas at low altitudes due to safety and noise from low level flying following urban rail and road corridors to key stations and suburban shopping centres (with localised land transport facilities and services) is plausible.

For regional areas the advent of more affordable aviation services could be profound, both in terms of intra-regional and inter regional services. Electric aviation intra-regional services for regional and remote Australian communities operating into regional hub airports with multiple major city services could reduce costs while increasing the accessibility and connectivity.

Recommended Actions

Actions recommended:

1. Widening the scope of the emerging aviation review to consider out to the 2040 technology horizon with specific consideration of potential fundamental technological innovations that will impact on short haul small PAX aviation within the next 10 years (2030).
2. An extended emerging aviation review should include:
    a. Research to understand the potential impacts on transport infrastructure and urban settlement patterns with the development of commercial short haul, small PAX aviation service
    b. Research to understand the potential impacts on industries such as tourism
3. Development of a national emerging aviation industry development strategy starting with a national review and audit of R&D and industry capability.

Biography

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Dr Michael Kane is a Research Associate at Curtin University Sustainability Program. Michael's research areas are future transport, city and regional planning, and knowledge economy. Michael's PhD thesis was on future cities, knowledge economy and urban transport planning. Michael works for the Queensland Government in innovation and economic development. Before this he was an adviser for the Minister for Planning and Infrastructure in Western Australia on land development, transport and strategic planning.

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