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Demonstration flights of hybrid electric aircraft

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Abstract

Due to the need of carbon reductions in the aviation sector, Ampaire, an electric aircraft company, demonstrated regional point-to-point flights with a retrofitted hybrid-electric Cessna 337, showing the ability of hybrid-electric aircraft to operate real-life routes in a distributed aviation system and reduce direct emissions by up to 38%.

Keywords: sustainable aviation, sustainability, zero emissions, SAF-electric, green aviation

1. Abbreviations

SAF	Sustainable Aviation Fuel
CAA	Civil Aviation Authority
DfT	Department for Transport
IP	Ingress Protection
P2P	Point-to-point

2. Introduction

In 2017, aviation was responsible for over 3.8% of the annual global CO_2 emissions [1]. With other industries reducing their carbon emissions drastically, the aviation industry must react. The Department for Transport (DfT) set the goal for net zero emissions in aviation to 2040 in their Decarbonising Transport report [2]. The UK DfT's goal is set 10 years earlier than the net zero goal set in the EU Green Deal [3]. Cutting direct emissions from the aviation sector can only be achieved by changing the energy source which is why many companies look into alternative fuels. The main three solutions to reduce carbon emissions are sustainable aviation fuel (SAF), hydrogen fuel and battery propulsion technology. A second market driver is that regional airline operators face serious economic challenges due to operating costs. Direct Operating Costs (DOC) make up around 50% of the total operating cost which includes fuel, maintenance, pilot, and aircraft ownership. Especially small airlines that operate small aircraft struggle with the direct operating costs since the income of the flight is based on the number of passengers. Therefore, a decrease in direct operating cost is necessary to make a business case for small airlines. Fuel and maintenance costs can be reduced by electrifying aircraft which comes at the

cost of the upfront investment needed for the aircraft. Yet, reducing fuel and maintenance costs will sooner or later, depending on the energy demand of the aircraft, pay off the higher initial investment of the airframe.
To overcome economic challenges for small airline operators and increasing the efficiency of small aircraft, a new opportunity arises with the advent of (hybrid) electric aircraft: a transformation of the Regional Air Mobility (RAM) market. This model has been discussed in the paper 'Regional Air Mobility' by NASA which looks at the many small, underused airfields available and the value of increased safety, accessibility and affordability of travel that they hold. The reduction in DOC that (hybrid)electric aircraft offer will make more point-to-point city pair connections economically viable.

3. Background

To address the challenges and opportunity discussed above, Ampaire Ltd. is part of two projects, the SATE project (Sustainable Aviation Test Environment) and the 2ZERO project (Towards Zero Emissions in Regional Airline Operations). Both projects have received funding from UK Research and Innovation (UKRI) through the Future Flight Challenge (FFC). The aim of the FFC is it to bring together new technologies in electrification, aviation systems and autonomy to advance air travel and demonstrate their potential for positively impacting mobility and climate.
The SATE project is based in Kirkwall, aiming to realise an aviation test centre for new technologies in real world operating conditions. Kirkwall was selected due to its tougher weather conditions which include high winds, fog, and heavy rain.
The 2ZERO project aims to decarbonise regional aviation. The project comprises three thrusts: 1) modelling and simulation of the aviation system (airline and airport operations), 2) aircraft integration and operations, and 3) flight demonstration. The project addresses not just the aircraft, but aims for ecosystem readiness with airlines (Loganair), airports (Exeter and Cornwall) and a regional development agency in the consortium in addition to industry (Ampaire and Rolls Royce) and academia (Nottingham). 2ZERO is aiming for a paradigm shift from the Hub-and-Spokes model to a point-to-point (P2P) "distributed" aviation model.
Ampaire is a 2016 founded start-up company that develops electric aircraft. Using a practical, compelling, and trusted approach, Ampaire starts by delivering hybrid electric aircraft by retrofitting existing airframes. In 2019, Ampaire's retrofitted Cessna 337 Skymaster demonstrated the technology developed by flying a potential airline route in Hawaii. The original Cessna 337 Skymaster has two inline 195hp IO-360-A engines. During the retrofit the front engine was replaced by an electric motor called Emrax 348 with 380 kW peak power, turning the aircraft into Ampaire's 'Electric EEL'. Ampaire is targeting the 9-seater market by 2024, and 19-seater by 2026.

4. Methodology

Modelling and simulation of realistic airline operations:
To understand the impact of the changes associated with introducing hybrid electric aircraft in a more P2P model, a model was built by Nottingham University of operations of current airline routes and hybrid-electric aircraft operations. Input from Loganair airline, Exeter, and Cornwall airports and Ampaire on a 9-seater as well as a 19-seater aircraft helped to create a realistic model. This model looks in detail at in flight, on ground and route planning activities and the adjustments needed to operate a hybrid-electric aircraft successfully and efficiently.
Proof of concept in realistic airline operations:
To prove that hybrid electric aircraft can operate new and existing air routes, specific routes were selected. Through the SATE project, which is based in Kirkwall, Ampaire demonstrated the Kirkwall to Wick route. This route is currently not covered by any airline, yet there is a mobility demand which is reflected in the number of ferry passengers. In 2019 over 520 thousand people travelled between the mainland and Orkney and Shetland Islands according to the UK Department for Transport Statistics.
Another route between Exeter and Cornwall Newquay was selected for the demonstration thrust of the 2ZERO project. Since the 2ZERO project looks at regional operations, a route from a peripheral regional airport to a more central airport was selected, with underdeveloped (electrical) train infrastructure to offer a clean, affordable, and fast connection.

To be able to fly the C337 demonstrator on these routes, a permit to fly was needed from the UK CAA. To obtain the permit to fly, the UK CAA and Ampaire UK have worked closely together, using the baseline of the FAA Experimental Type Certificate for market survey flights. The permit to fly was successfully obtained.

System efficiency:

Apart from proving that Ampaire's hybrid electric aircraft can provide service on the selected routes, the economics, including the fuel savings, behind the operations were analysed. To calculate the fuel savings, the fuel consumption for the baseline aircraft (with two combustion engines) was calculated and compared to the fuel consumption of the hybrid aircraft (with one combustion engine and one electric powertrain) for the same route and mission profile.

To calculate the fuel consumption of the baseline aircraft, a flight profile was determined based on the flights of the hybrid electric aircraft. Subsequently, the fuel consumption during different phases of the flight was calculated, using the part throttle fuel consumption graph for the specific engine as seen in the flight manual.

The hybrid fuel and electricity consumption were measured as the pilots took the time and the mechanic took note of the fuel before and after flight. The fuel level was measured using a dipstick. Electric energy consumption was measured using battery state of charge.

5. Findings

The flights performed through the SATE project were performed between Kirkwall and Wick showing that the route can be covered by a hybrid electric aircraft. The door-to-door travel time from the city centre of Wick to the city centre of Kirkwall using cars for transport to and from the airports and flying with the hybrid electric aircraft was 40 minutes, while a car and ferry would take 2 hours and 20 minutes. Newquay, a region that operates Public Service Obligation (PSO) Routes due to being a peripheral region, would benefit from having a connection flight to Exeter and other larger cities around. Additionally, further connections to Land's End (demonstrated) and Scilly Islands (not demonstrated) could aid the development of affordable, clean, regional connectivity from the test flights we have learnt that the route between Exeter city centre and Newquay city centre can be covered in around 1.5 hours which is the same length as the road transportation which takes 1.5 hours. Whilst on this route there is no improvement in time, operating this route would decrease the number of cars on the road and help lowering traffic peak demands. Instead of cars with typically one or two passengers, a full 9-seater aircraft could get 5 to 9 cars off the road. The door-to-door route Exeter city centre to Land's End takes 2 hours 20 minutes by car and 1 hour and 40 minutes by a mix of aircraft and first/last mile road transportation.

All point-to-point routes demonstrated only required a recharge of the battery at the base airport. Whilst an additional charger was placed at the destination airports, enough energy was available to take off again and return to the base without recharging the battery. The amount of charge left varies with the pilot's choice of using the electric motor. If the pilot decides to use the electric motor as much as possible before touching reserves or perform multiple take-offs without charging in between, the charging time increases. The charging time depends on the possible charging rate of the charger and battery.

In close coordination with the CAA, only flights in Visual Meteorological Conditions (VMC) were performed for the demonstration flights. The permit to fly was restricted for the demonstration period and for the selected routes. Routes had to be submitted with the application and large built-up areas were to be avoided. Even though the flights were executed in August, the weather restricted the operations heavily in Scotland. These restrictions would be solved for a product when fully certified since then IFR operations can be allowed. To ferry the aircraft between Wick and Exeter, a record-breaking flight for a hybrid electric aircraft was set, of 418 Nautical miles.

When analysing the fuel consumption from the two routes shows fuel savings of 38% on the route between Wick and Kirkwall and 37% on the route between Exeter and Newquay. The electric energy was mainly used during take-off and climb, which is the most energy demanding flight phase. A sufficient reserve was kept for a second climb in case an airport diversion or missed approach is needed, similar to real operational requirements for airlines. The demonstration flights have shown it's viable for a hybrid electric aircraft to meet such requirements.

6. Discussion

Flying the P2P routes during the summer of 2021 was mainly done to demonstrate that the chosen routes can be serviced by hybrid-electric aircraft, with realistic energy usage profiles. All flights on the demonstration routes were performed without any disruption and showed that the aircraft can easily fly the distance under the set conditions. The demonstration also showed that a recharge of the battery is not required during every touchdown but every second or third, reducing the turnaround time drastically. Through modelling and simulation of routes, even more efficient operation profiles can be developed and generate operations based on the airlines requests such as maximise fuel savings or increase battery life or shorten turnaround times.

The permit to fly heavily restricted the demonstration to weather conditions and routes. To progress towards certification of the concept, it should be demonstrated that the routes can be operated with a hybrid-electric aircraft in more diverse weather conditions, including IMC and precipitation. To fully prove that hybrid-electric aircraft are ready to fly the routes, a demonstrator with the according IP rating should be built and show that it can operate under the same weather conditions as current same sized commercial aircraft. Ampaire aims to achieve this with aircraft that will subsequently be certified as product (e.g., Cessna 208 or Britten Norman Islander).

Note, that whilst hybrid-electric aircraft operate under the same safety rules as other aircraft, operations differ from fossil fuel burning aircraft since two kinds of energy can be managed. This leads to larger degrees of freedom for the airline, depending on the route network. Energy strategies impact operational fuel costs, as well as charging strategies, turn-around-times, and the lifetimes of batteries.

All flights prove that a significant reduction in fuel consumption can be achieved by retrofitting existing aircraft, which means that next to emission reduction also a reduction in operating cost can be achieved. Electric motors additionally have lower maintenance costs. The aircraft used, was primarily built to demonstrate the propulsion technology, so the fuel efficiency was not optimised. Fuel consumption could be further reduced by choosing different (newer) combustion engines and opting for different fuels. By using Sustainable Aviation Fuel instead of normal kerosine, net CO2 emissions can be further reduced. By converting aircraft that still use Avgas to SAF/electric, also lead emissions can be eliminated, which is a highly desired step from government side. Other optimisation processes could be conducted to increase fuel efficiency. Also, retrofitting aircraft will never reach the same fuel efficiency as clean-sheet designs, yet the certification process is simpler which makes retrofitting the fastest path to market and an ideal demonstrator for the technology in this pioneering phase. Also, the demonstrator aircraft used was made to prove the technology works which means an optimised aircraft would have much higher potential regarding fuel savings.

As mentioned, hybrid-electric aircraft have the potential to be near carbon neutral if sustainable aviation fuel is used and the electricity used comes from a renewable source. Reducing direct emissions and therefore bringing the aviation industry closer to net zero is very important. The environmental benefit of decarbonising the aviation industry can be easily overlooked since 3% of global emissions does not sound too much but in fact it is equivalent to over 900 million tons of carbon. Most of this is emitted by large, medium, and long-haul jet aircraft for which SAF is the only viable alternative at the moment. Small aircraft, much like the birth of flight over 100 years ago, will however start a revolution as better batteries will become available over time. Renewable electricity is the cleanest form of energy. Hydrogen requires electricity to be generated and has more losses in the entire process from source until propulsor (liquifying, transport, cryogenic storage, converting back to electricity). Synthetic SAF, in turn requires recapture carbon and hydrogen to be generated, and SAF still emits other particles such as NOx.

A reduction in operating costs also allows operators to offer cheaper and more frequent flights which would be a huge benefit especially for remote locations where communities rely heavily on air transport. This makes new routes economically viable, to power the distributed aviation model where more 2nd and 3rd tier airports are used in a P2P network.

Currently, the most common model of operation in Europe is the hub to spoke model in which an airline has a base airport from which it offers flights based on a schedule determined by the airlines. New DOC and emission savings allow for the P2P system to be leveraged and invested in instead. The advantage of the P2P model for airlines is the ability to compensate for the higher initial investment needed for hybrid-electric aircraft by offering more frequent flights with lower direct operating costs, paying off the

initial investment and generating higher returns afterwards. To maximise the returns by flying at maximum capacity, a demand and supply model could be introduced in which the airline offers P2P routes based on the need communicated by the public. Introducing short-haul point-to-point routes is also in the interest of the public and government as emissions and congestions can be reduced by covering these routes with hybrid-electric aircraft instead of cars filled with one to two passengers.

7. Conclusion

All in all, the demonstration of the flights has shown that hybrid-electric aircraft are able to fly point to point routes against airline requirements. The energy savings and associated cost savings bring economic viability to a P2P model connecting much more city pairs. This should be part of the future of aviation. The potential of hybrid-electric aircraft is large: remote communities can be better connected to larger cities; small airlines can make stronger business cases and carbon emissions can be significantly reduced.

8. References

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