Challenges of achieving hybrid and electric flight

The current status and future of battery gravimetric energy density: how the industry's environmental requirements are addressing CORSIA's objectives to reduce CO2 emissions.

The initiative in the aviation industry to evaluate electric flight, via proof of concept and test beds, and realise electric propulsion, through hybrid and fully-electric solutions, continues to advance.

Roland Berger, the independent global consultancy firm, is tracking 190 different programmes, an increase of nearly 20 since May 2019.

Statistics provided from its database indicate distribution of electric aircraft projects by aircraft type as follows: 50% for urban air taxis (UAT); 40% for general aviation (GA); 10% for regional aircraft; and a few attributed to large commercial aircraft (LCA).

Geographical spread is 40% for Europe, 40% for North America, and 20% for rest of the world.

Of the 190 projects, 70% are based on all-electric propulsion and 30% hybrid propulsion. Criteria for inclusion in the database are projects that are intended to fly or have a commercial use; and exclude rig tests to be performed on the ground.

This impetus can, to a certain degree, be attributed to the urgent need for aviation to reduce anthropogenic carbon emissions: the industry emits about 900 mega tons per year, equal to 2.4% of global CO2.

Simulations conducted by Roland Berger forecast that this share could reach 24% by 2050, assuming the trajectory of evolution continues at current pace with no production of hybrid or electric aircraft.

International civil aviation has been excluded from United Nations (UN) agreements on climate change, namely the Kyoto Protocol and COP21 Paris Agreement. However, the International Civil Aviation Organization (ICAO) has set up the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

CORSIA's objective is to stabilise net CO2 emissions at 2020 levels, and further to reduce net CO2 emissions to half of what they were in 2005, by 2050. The sector is also committed to driving advances in technology, operations and infrastructure to continue to reduce its emissions. Offsetting is only a short-to medium-term initiative to help achieve climate targets.

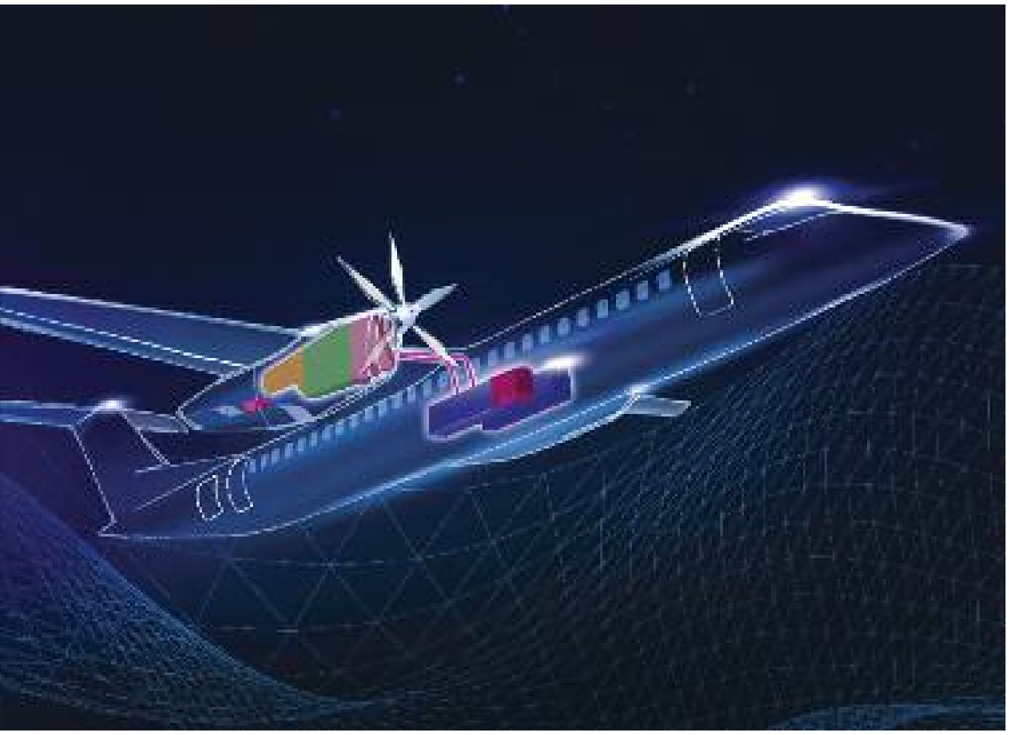
"There are two distinct trends in the industry. The first is the long-term evolution towards the More Electric Aircraft (MEA). This has become well established over the past 30 or 40 years, where with every generation of new aircraft, you have more systems that are electrically powered, and fewer that are hydraulic, pneumatic or mechanical. The second is electrical propulsion, which is wholly new and potentially revolutionary. This comes in two high-level types. One is hybrid, and the second is all-electric," says Robert Thomson, partner at Roland Berger.

Results obtained from Roland Berger's survey of aerospace and defence professionals underscores a high standard deviation from the mean for entry into service (EIS) dates, and illustrates the wide range of views. "In our latest survey of the industry, we asked people when they thought a hybrid electric aircraft larger than 50 seats would make its first revenue-earning flight from London to Paris. The median answer was 2030 to 2035. For an all-electric aircraft larger than 50 seats, the median answer was 2040 to 2045," says Thomson.

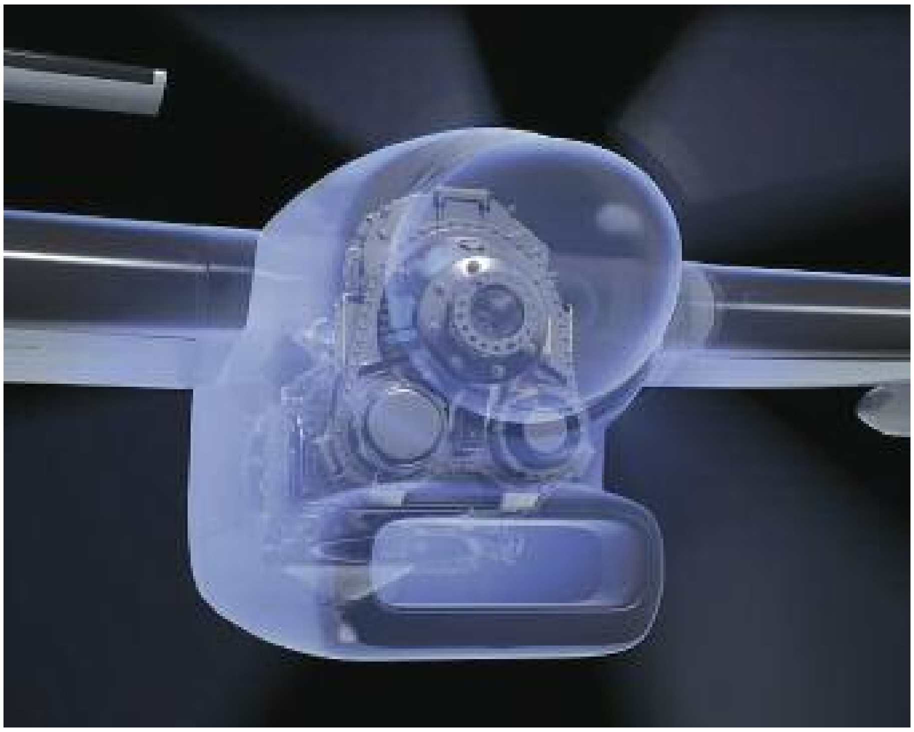
Thomson highlights the infancy of the technology and the amount of power needed to fully effect electric propulsion as accounting for 90% of the UAT and GA programmes. Weight is also one of the principal factors.

"For a large commercial aircraft, you might need 40 or 50 megawatts (MW) of electrical power to take-off. That equates to a huge weight of electric motors, power electronics, cables and ancillary equipment. If you look at the weight of electric motors today compared to what might be needed for something that could fly, we are still some distance away. The weight of the electrical system would completely mask any benefit you might get from moving away from a gas turbine. At the smaller end, the power involved might be a few hundred kilowatts. That is within the capability of today's technology," explains Abigail Howell, consultant at Roland Berger.

"Almost certainly where hybrid will start is with a largely conventional



Project 804 is a hybrid-electric X-plane initiative from United Technologies Advanced Projects (UTAP) based on a Bombardier Dash 8-100 platform. Its mission is to achieve flight by 2022.



Project 804 delivers 2 MW of power in a 50 - 50 split between a 1 MW engine and a 1 MW electric motor working as a parallel hybrid-electric propulsion system.

engine, but supplemented by electric power at take-off. The advantage of that is you can size the engine for cruise, which makes it much more efficient, and give it a boost at take-off. Although you need to carry the batteries, the reduction in engine size means you still get a net saving in fuel burn over the total flight. The other big part of the equation for hybrid-electric is the need for novel aircraft architectures," adds Howell.

Fundamental to the transformation of electric flight is the need to bridge the technology gap to the power output required, delineated by battery gravimetric and volumetric energy density. Today this is encapsulated by how much weight you can afford to carry in the trade-off between weight and range. Technology roadmaps at the forefront of research and development (R&D) are considering neoteric compositions to aggrandise energy density such as lithium-air, lithium-metal, lithium-water, and lithium-sulphur to overcome the poor performance of traditional intercalation-based materials.

"Energy density is under development. The top end of the range is 1,000 to 1,500 watt-hours per kilogram (Wh/kg), with novel chemistries, but most companies are in the 400 to 500 Wh/kg range. The problem is that at present energy density only gives a very short range. That is fine if you want to fly 300 or 400 miles, but most people want to fly a bit further. 500 Wh/kg is the minimum for aviation that everybody says is needed to make things viable. Even at that level, we are still at least one order of magnitude lower in energy density than kerosene. I think lithium-ion batteries attaining more than 250 Wh/kg is conceivable in a five-year time span. The cost of a lithium-ion battery pack is expected to decline by 60% by 2030, in part due to growing production of batteries used by the automotive industry," says Thomson.

Recently announced initiatives have seen a number of unique partnerships forged by aerospace incumbents to profit from the synthesis of technical capabilities.

Project 804

United Technologies Advanced Projects (UTAP), at the heart of United Technologies Corporation (UTC), is channelling the deep aerospace background between UTC subsidiaries, Collins Aerospace and Pratt & Whitney, towards its first project, which is both an advanced technology and a hybrid-electric X-plane product demonstrator.

Designated Project 804 (P804), the platform is based on a Bombardier Dash 8-100. Maintaining the existing airframe, systems, and propellers, one side is retrofitted with a 2 MW class hybrid-electric propulsion system, and the addition of new battery technology in the cabin. The engine and electric motor will each generate about 1 MW of power in a parallel hybrid configuration.

"The mission of UTAP, and the intent of P804, is to be disruptive in the industry. We want to lead. We want to be able to build and test these high-powered systems and develop that learning. Our intention is to make sure that we can prove these things out. P804 is the perfect test bed to bring together all of the capabilities of United Technologies," explains Greg Winn, general manager at Collins Aerospace.

The demonstrator's architecture is expected to provide up to 30% block fuel savings on a typical one-hour mission, with a commensurate reduction in CO_2 emissions. A percentage of the fuel savings will be attributable to advancements in engine technology. The upshot of carrying the batteries will see a slight trade-off between weight and range with the latter estimated at 600 nautical miles (nm), which would otherwise be a typical mission for this type of aircraft.

Flight is targeted by 2022; the initial propulsion Preliminary Design Review (PDR) was completed at the end of June 2019. The programme will lend itself to future applications, such as retrofitting and clean-sheet design.

The Dash 8 is ideally suited to a parallel hybrid setup, requiring twice as much power during take-off and climb than it does in cruise. The engine, which is being developed by P&W, can be optimised for cruise efficiency, because take-off and climb will be augmented by the electric motor. The battery can therefore be sized for a high-power, short-duration phase of 20 minutes and contained within the maximum take-off weight (MTOW).

"The electric motor and engine are connected via a combining gearbox, and can either run together or independently of each other. The engine will run at peak efficiency during all phases of flight and throttle back on descent," says Winn. "The electric motor will only be active during take-off and climb. As we get towards the top of climb and into cruise, the electric motor will shut off, and remain off throughout the descent phase. It would only switch back on to enable in-flight recharging.

"For the purposes of this demonstrator, we are targeting lithium-ion battery chemistry and using state-of-the-art advanced cells. We have to manage high power density and voltages which bring a lot of unique challenges to making this safe on an airplane," says Winn.

"The pacing item for the industry right now is battery capacity. Power density has got to improve in order to start unlocking the ability to do hybrids, or all electrics," continues Winn. AC