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HOW AIRCRAFT ELECTRIFICATION IS SHAPING THE FUTURE OF MILITARY AVIATION

U.S. Army Combat Capabilities Development Command Aviation & Missile Center's initial evaluation flight of the BETA ALIA 250C, an eVTOL aircraft developed by BETA Technologies.

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND AVIATION AND MISSILE CENTER

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By Matt McLaughlin

In more than a century of aviation in the military, the aircraft have evolved immensely. From hydrogen-filled, tethered balloons used in the Civil War to the large-scale use of airplanes for a variety of tasks in World War I, this evolution continues with modern aircraft that are utilized as fighters, transports, spies, and even hospitals.

The technology used to support these aircraft has advanced as well. One of the next steps in this evolution is electrification, which simply refers to the use of electric power for the operation of aviation systems. Civilian and military aircraft developers are pursuing different approaches to electrification:

The more electric aircraft relies on the electrification of some elements of the aircraft, instead of using hydraulic, mechanical of pneumatic actuators. In this approach, the aircraft still runs off fuel, but uses electric power for actuators to run systems such as flight controls and landing gear, among others.

The full electric aircraft uses electricity to power all systems, including propulsion. This more advanced approach is considered a further step in the evolution of electrification and poses a variety of challenges to developers.

In general, aviation developers are making incremental progress toward electrification. As technical challenges are overcome, more systems can be electrified, with propulsion posing the final hurdle.

“The more electric aircraft is getting at the flight systems themselves, including braking systems, flight controls, ailerons, rudders, where you're getting rid of these heavy mechanical, pneumatic, or hydraulic systems, which also have their own maintenance challenges,” said Robert C. Haywood, global product director for capacitors and industrial cables with W. L. Gore & Associates, a global materials science company that works in aircraft electrification. “Weight is a primary driver. If you can get more electric power on board by generating it from the jet propulsion system, then distributing that electric power to drive these systems, you get that weight out of the overall aircraft."

Civil aviation initiatives are leading the technological development of electric propulsion, but several military initiatives are under way as well. The development of fully electric aircraft still faces significant hurdles, some of them technical challenges such as power and thermal management. Other considerations include obtaining approval from the Federal Aviation Administration for new aviation technologies.

In the military space, much of the attention on fully electric aircraft has gone to electric vertical takeoff and landing (eVTOL) vehicles, which use electricity from batteries to power rotors. If successful, the development of eVTOL would provide a valuable complement to the helicopters that have been a staple of military aviation for decades.

Not only would such an aircraft support the Army's Climate Strategy by producing lower levels of carbon emissions, but potential benefits also include design flexibility, reduced maintenance, reduced acoustic signatures, and lower support costs. While not a direct replacement for helicopters, eVTOL could complement the capabilities of conventional rotorcraft. The Army conducted its first test flight of an electric aircraft in July 2022.

"The Army is very interested in electrification for a variety of reasons including the potential to reduce the need to transport large quantities of fuel," said Dr. James Kirsch, director of the Software, Simulation, Systems Engineering and Integration Directorate of the Army's Aviation and Missile Center.

AFWERX Airmen gathered at Duke Field on Eglin Air Force Base, Florida, to witness the delivery of BETA's ALIA electric aircraft to the Air Force for testing.

JENNIFER BRYANT/U.S. AIR FORCE

The Benefits of Electrified Aviation

The successful deployment of electrified aircraft would bring numerous advantages over some current aircraft. Chief among these benefits would be a reduction in the need for maintenance, which could be achieved by either a more electric or fully electric aircraft. Because electric motors have fewer moving parts, they require less maintenance than the systems they would be replacing, such as hydraulic, pneumatic or even propulsion systems. Thus, they would require less attention from military technicians and be available more regularly by avoiding scheduled and unscheduled downtime – which would be a particularly valuable benefit in a warfighting environment. This reduction in maintenance needs would also reduce costs associated with maintenance.

The reduction of carbon emissions would be another major advantage for both more electric and fully electric aircraft. Aircraft produce roughly 2.5 percent of global carbon emissions, according to research estimates. The more aircraft systems that can be powered by electricity, the more these emissions can be reduced, which would diminish the environmental impact of aviation as well as shrink fuel costs.

Electric-powered aircraft also produce a significantly reduced acoustic signature compared to conventional aircraft. Quieter aircraft would represent a benefit for civil aviation in urban areas but potentially an even greater advantage in some military applications.

As the technology behind electrified aircraft continues to mature, the first steps will be increasing the numbers of systems running on electric power. Each incremental improvement paves the way toward a fully electric aircraft.

The Challenges of Aircraft Electrification

Any progress toward increasing the number of electric systems, on the way to fully electric aircraft, requires developers to overcome some significant challenges.

"Whether it's civil or DOD, it's really the same physics, and it's the same technical challenges. It really comes back to power density at the end of the day," Haywood says. "How do you get more electrified power on board without adding significant weight or size, space? Obviously, all optimized with cost as well. Power density is a key challenge."

The challenge is complicated, Haywood said, by the fact that efforts to address power density via one factor inevitably affect others. For example, increasing the voltage used in a system to deliver more power, or increasing the frequency in power conversion to improve power density, can create the potential for arcing and greatly increase the heat created. High temperatures can lead to breakdowns in equipment.

In some engineering situations, the need to increase electric power might be solved by expanding the size of the system delivering the power. However, this increases weight, which is a limiting factor in aviation.

Ultimately, as more aviation systems are moved to electric power, aircraft need to be able to create, store and transmit more electricity while minimizing weight and handling higher temperatures. This requires the development of new technologies and novel components made with robust materials that can handle the challenging conditions created by electrified aircraft.

Developing these new components and technologies requires innovative thinking. Aviation as an industry continues to evolve, but it frequently relies on decades-old technologies. Advances in electrification will require new materials that move beyond legacy components. For example, aviation engineers are working on advanced insulation of electrical system wiring with materials that can handle higher voltage levels while eliminating the potential for partial discharge arcing issues.

Instead of simply increasing the thickness of the insulation in wiring, which adds weight and takes up valuable space in aircraft, engineers are testing new materials. Fluoropolymers such as polytetrafluoroethylene (PTFE) show significant potential to provide the insulation capabilities needed in these environments. PTFE provides excellent breakdown voltage resistance, and its low dielectric loss helps prevent the partial discharge of electricity.

Power conversion represents a significant challenge in electric aircraft. Direct current from a power source must be converted to alternating current to drive the motors involved

An experimental electronic vertical take-off and landing aircraft is parked at taxi way following a ground test at Edwards Air Force Base, California.

HARLAN HUNTINGTON/U.S. AIR FORCE

in actuating systems such as flight controls or braking. The aviation industry is considering innovative approaches from other electric vehicles such as automobiles to address this challenge, but the solution must be able to handle even more extreme temperatures.

Wide bandgap semiconductors from materials such as silicon carbide and gallium nitride enable operation at much higher voltages, frequencies, and temperatures than conventional semiconductors. However, this introduces more heat to the operation. Stronger cooling systems to address higher temperatures add more weight, so engineers are looking at solutions that may remove the need for cooling altogether. For example, capacitors that can operate at temperatures as high as 200 degrees Celsius could replace legacy polypropylene capacitors that must be cooled to around 80 degrees Celsius.

As advances are made in new materials and technologies for increasing the electric power that aircraft can use, engineers are moving closer to the goals of fully electric military aircraft.

Progress in Aircraft Electrification

Much of the progress toward the goal of fully electric aircraft is being made in civilian aviation. Dozens of companies are working to develop electric aircraft as the industry makes strides toward achieving net zero carbon emissions by 2050, a target established in 2021 by members of the International Air Transport Association.

Aviation depends heavily on fossil fuels and produces massive amounts of carbon emissions. Electric aircraft will help the industry reduce fuel consumption and emissions. Civil aviation manufacturers are producing hybrid electric aircraft that are powered by batteries and also have engines that consume conventional fuel. Some of these aircraft have limited range compared to conventional aircraft, topping out at roughly 125 miles for electric-only flight and up to 500 miles for hybrid use, making them suitable for regional travel.

The progress in civil aviation appears to be accelerating the pace of development and innovation on the military side. In October 2023, a small aviation manufacturer delivered the Air Force's first manned electric aircraft. The aircraft, which has vertical takeoff and landing capabilities, flew more than 1,700 miles from Vermont to Eglin Air Force Base in Florida, where it was to undergo further testing.

The aircraft was developed as part of the Air Force's Agility Prime program, which aims to work with academia, industry and other partners to field new vertical lift vehicles. Launched in May 2020, Agility Prime is intended to utilize advanced manufacturing and materials to develop large distributed electric or hybrid-electric propulsion systems and increase the use of automation for simplified operation. Among its objectives are to create aircraft with zero emissions as well as vehicles that do not need runways for takeoff.

In addition to testing manned electric aircraft, Agility Prime – which is run by AFWERX, the innovation arm of the Air Force – is also examining the use of remotely-operated electric aircraft. The initiative is exploring opportunities for collaborative testing and development of new technologies and working with partners such as NASA and the Federal Aviation Administration to address regulatory issues.

The Air Force is not the only military service exploring the use of electric aircraft. The Army also is looking into eVTOL aircraft as part of its continuing effort to field state-of-the-art technology as well as to reduce its environmental impact. This includes partnerships with civilian federal agencies as well as working with the Air Force on Agility Prime.

"There's always a need in aviation for better speed, more payload, more range, better efficiency, lower cost," said David Friedmann, an aerospace engineer with the Army Combat Capabilities Development Command Aviation and Missile Center's Technology Development Directorate.

Electrified Aircraft in Military Applications

Perhaps the two most important objectives of the military's use of electric aircraft are to reduce carbon emissions and to minimize maintenance needs.

Reducing carbon emissions is an objective that yields advantages beyond environmental benefits. In April 2023, the Department of Defense released its Plan to Reduce Greenhouse Gas Emissions, which states that reducing emissions can create a warfighting advantage for the U.S. military and its allies.

"Increasing the use of electricity to power land, sea (surface and subsurface), air, and dismounted soldier platforms has the potential to improve efficiency and could expand options for powering the force," the report states. "The ability to use multiple sources of electricity — many of which may be low carbon — can increases resilience against the disruption of any single source. Furthermore, as commercial markets shift away from fossil fuels, electrifying DoD forces will reduce dependencies on potentially outdated technologies and supply chains. Electrification can also deliver operational capabilities by, for example, enabling flexible power to support an increasing number of lethality and survivability systems integrated into vehicles and other platforms."

The report cites aircraft electrification under the Air Force's Agility Prime initiative as among efforts to improve operational energy efficiency performance.

The Army has its own Climate Strategy, published in February 2022, which sets goals for reducing net greenhouse gas pollution by the Army by 50 percent (compared to 2005 pollution levels) by 2030. It further targets achieving net-zero greenhouse gas emissions by 2050. Aircraft electrification is one of the initiatives the Army intends to pursue to achieve these objectives.

While emissions goals are important, the reduction in maintenance cycles is the more immediate benefit of aircraft electrification. The incremental improvements of the more electric aircraft will result in lower maintenance costs for aircraft, greater uptime and improved reliability while reducing demands on personnel.

The achievement of fully electric aircraft will bring even more use cases. Military leaders see applications for eVTOL aircraft in reconnaissance, transportation, and logistics. These aircraft can be used to transport troops and equipment in remote locations or places where access is challenged. The Air Force sees additional possible uses in firefighting, search and rescue, humanitarian aid efforts and medical evacuation. Further, the quietness of electrified propulsion systems can provide a tactical advantage, making them more difficult to detect in warfighting and other scenarios. As the technologies behind electrified aircraft improve, it's likely that the number of uses cases for them will expand.

The Future of Military Aircraft Electrification

The continuing evolution of aircraft electrification will have a disruptive effect on military aviation. As engineers make advancements in bringing new materials and technologies into aviation, the results likely will take the industry to unprecedented places.

History is a powerful force in industries such as aviation. Legacy thinking holds a strong influence over what happens going forward, but breakthroughs in aircraft electrification are likely to come from unexpected sources such as the numerous small startup firms that are participating in the Air Force's Agility Prime initiative.

"We are on the verge of technological disruption," Haywood said. "I think an open mindset is needed because full electrification is really uncharted territory."

DoD and the civil aviation industry are looking to solve technical challenges such as power density and size and weight limitations with new components that have not yet proven themselves in testing. The incremental progress they make in addressing these challenges brings them one step closer to achieving the vison of a fully electric aircraft.

Once this goal is reached, the next step will be to figure out how best to use electric aircraft to meet military objectives. A variety of manned and unmanned use cases for electrified aviation already exist that can help military services operate more efficiently and effectively, both in wartime and peace. The next challenge will be finding the new ideas that open additional missions for these aircraft. **DN**