Challenges of the More Electric Aircraft

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(EMA) to replace hydraulic actuation continue to progress, not all applications are suited for replacement at this time. Demanding applications such as landing-gear retraction for large aircraft still favor hydraulic actuators for three key reasons. To begin with, the retract actuator has to be packaged in a way that usually results in poor mechanical advantage, requiring very high force density, on the order of hundreds of thousands of newtons. This is not an insurmountable task to overcome for an EMA, but it does come at a size and weight impact. Additionally, while the actuator is not designed to be in the structural load path, deflections of the landing gear often require some compliance in the actuator. Hydraulic actuators have a sufficient amount of compliance to limit the peak stress when subjected to impact loads. EMAs are inherently stiff by design, which drives stress to unacceptable levels if not taken into account. Finally, hydraulic actuators easily fail in a passive damping state, whereas EMAs do not. While it is easy to add active damping to an EMA system, failure of the motor controller renders damping inoperative. In the event of a failure, the dampened state is preferred for many applications on the aircraft, including the landing-gear actuation system.

However, even if it is not feasible to replace a hydraulic actuator with an EMA for a given application, it does not mean that we keep the status quo. Instead of large, engine-driven pumps, which are at the heart of a centralized hydraulic system, we can take advantage of electrical systems for ease of distributing the hydraulic power. Distributed hydraulic systems using remote hydraulic power sources (electric motor-driven pumps) offer potential benefits including weight savings and safety improvements (minimizing impact of any one hydraulic failure). Although an electric motor-driven pump is conceptually a simple system, it has many of the same requirements of a complex flight control servo system. Each must use power-dense electric machines and power electronics that can be produced for an acceptable cost.

Optimizing technology at the aircraft level versus the component level requires detailed trade studies with the airframer and supplier to evaluate the pros and cons of a given technology. As another example, an EMA sharing the same performance capabilities of a hydraulic actuator may be heavier and have a higher initial cost but still be the best choice. The integration of the EMA in the system may produce an overall lighter solution or lower cost at the aircraft level due to the elimination of hydraulic components (valves, hydraulic fuses, accumulators, etc.). Even if the system is heavier with the EMA, it still may represent the best choice because of the added functionality or relative ease of maintenance. The Boeing 787 airplane uses electric brakes (EMAs) versus conventional hydraulic actuation. In general, the individual EMAs weigh significantly more than the equivalent hydraulic actuators at the brake stack, but the overall system gain surpasses the individual component difference on the 787.

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One of the main goals of the MEA trend is to increase the overall vehicle efficiency. Vehicle efficiency is not simply measured in terms of power output for a given power input but rather a means of optimizing the sum of all systems on the aircraft. None of these challenges are new or isolated to the aerospace community; they just have different weighting criteria used to assess their merits. In fact, there are common denominators in the push to electrify all transportation systems. All of these systems demand higher power densities, higher reliability, more functionality, and lower costs. The multidisciplinary challenge we face is how much "More" is the right amount in the MEA.

Biography

Nick Nagel (*njnagel@triumphgroup.com*) is the director of research and development at Triumph Aerospace Systems, Seattle, Washington, where he works with both electromechanical and hydraulic actuation systems. He is also an affiliate professor at the University of Washington, where he teaches courses in electric machines, drives, and controls. He has more than 20 years of experience in research and teaching with a focus on control of electric machinery.

Challenges of the More Electric Aircraft

By Nick Nagel

COMMERCIAL AEROSPACE has typically been fairly slow to adopt new technology when compared to other market segments. This movement is not due to a lack of vision or progressiveness but rather the constraints of the market. Commercial aircraft are designed to last for decades, not years, so the technology selected for any application must continue to be viable for its life span. Additionally, regulatory and safety requirements place stringent rules on any new technology introduced. But despite the challenges of new technology introduction, there has been a wealth of electrical system developments in the pursuit of the More Electric Aircraft (MEA).

This technology push represents an exciting time to be an electrical engineer in the aerospace community, but we must not forget the fact that the challenges in front of us are truly a multidisciplinary engineering problem. The MEA initiative is not, or should not be, focused on the arbitrary replacement of current hydraulic systems with all-electric systems, at least not until the all-electric system proves itself the better candidate. Instead, a disciplined systems approach must be used to determine the technology that provides an optimal solution at the aircraft level.

Nick Nagel.

Aircraft have increased power generation, distribution, and consumption. The most recent aircraft have increased electrical power by an order of magnitude compared to just two decades ago. But modern power systems have eliminated constant-speed transmissions, which maintained generator operation at a fixed frequency. Without the constant-speed transmission, the engine-driven generators are operated over more than a 2:1 speed range. This means that many applications historically run with conventional three-phase induction motors are now replaced with power converters, inverters, and permanent-magnet synchronous motors. For safety-critical systems in which a failure would be catastrophic, designs must meet a probability of failure of fewer than one in 1 billion failures per hour. This requirement can only be met with redundancy in complex electronic systems. While redundancy is used to mitigate probability of failure risks, it does so at the expense of reliability. Adding more components means there are more things to fail. This ultimately reduces reliability.

Aircraft have increased power generation, distribution, and consumption.

While converting to complex electrical systems has its share of problems, it is not without benefit. Increasing component count through redundancy may reduce the calculated reliability, but it may also increase availability (the ability for the aircraft to depart as scheduled). Availability is an extremely important measure for airline operators. Also, the increase in electrical power has reduced or eliminated the need for hydraulic and pneumatic power. Pneumatic power is generated from bleed air systems on the engine but is done so at very poor efficiencies. The bleed air system is used in cabin pressurization, air conditioning, and icing protection. According to the Boeing *Aero* quarterly publication, replacing the bleed air systems with electrical systems can save roughly 35% of power from the engine, clearly highlighting some of the benefits of the MEA.

While the developments in key areas (power electronics, electric machine design, and controls) enabling electromechanical actuation

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