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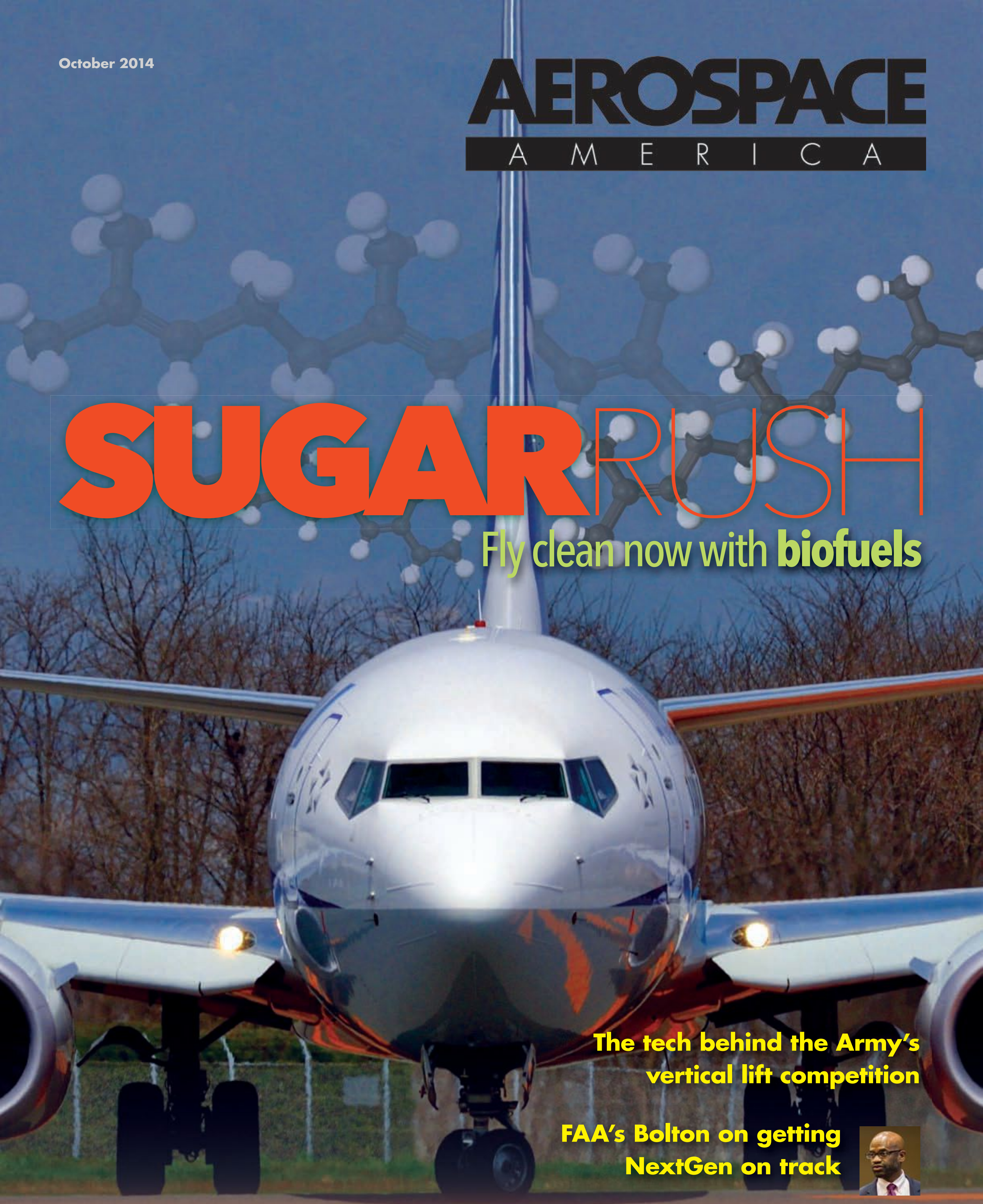

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A power system — reimagined

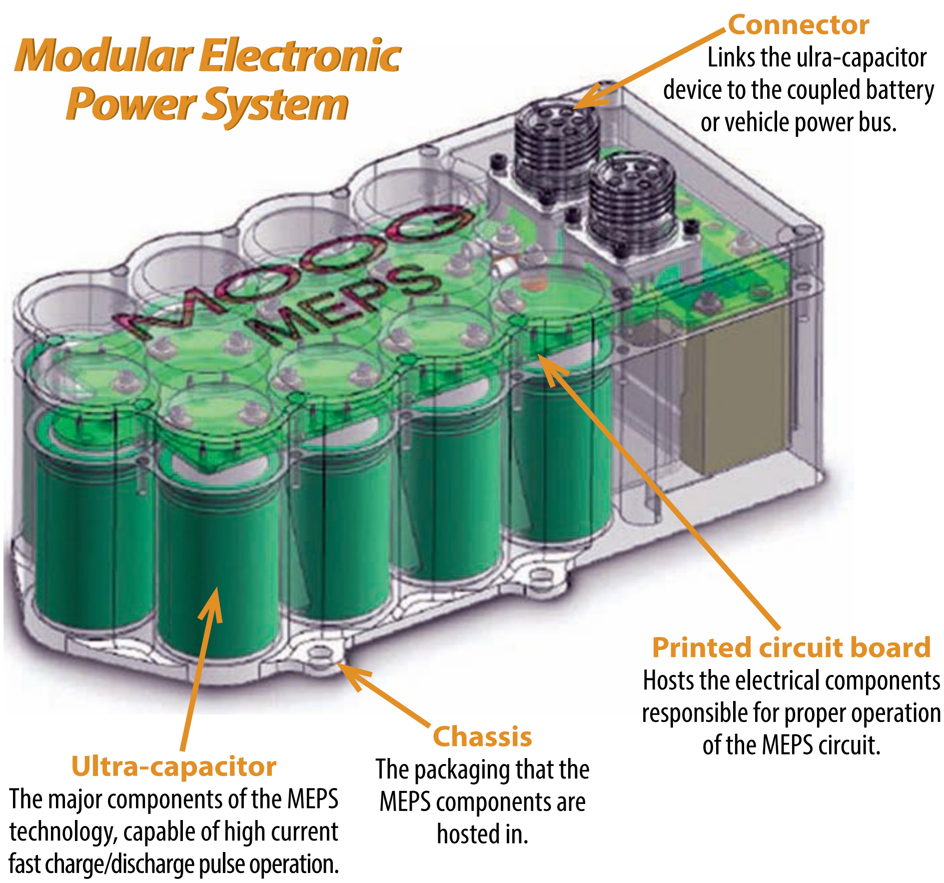
Rocket makers are always looking for ways to shave kilograms out of their designs so they can launch bigger sat-ellites or more payloads for paying customers. Moog engineers Jonathan Kasper and Greg Semrau describe research on a power concept that could do that and possibly much more.

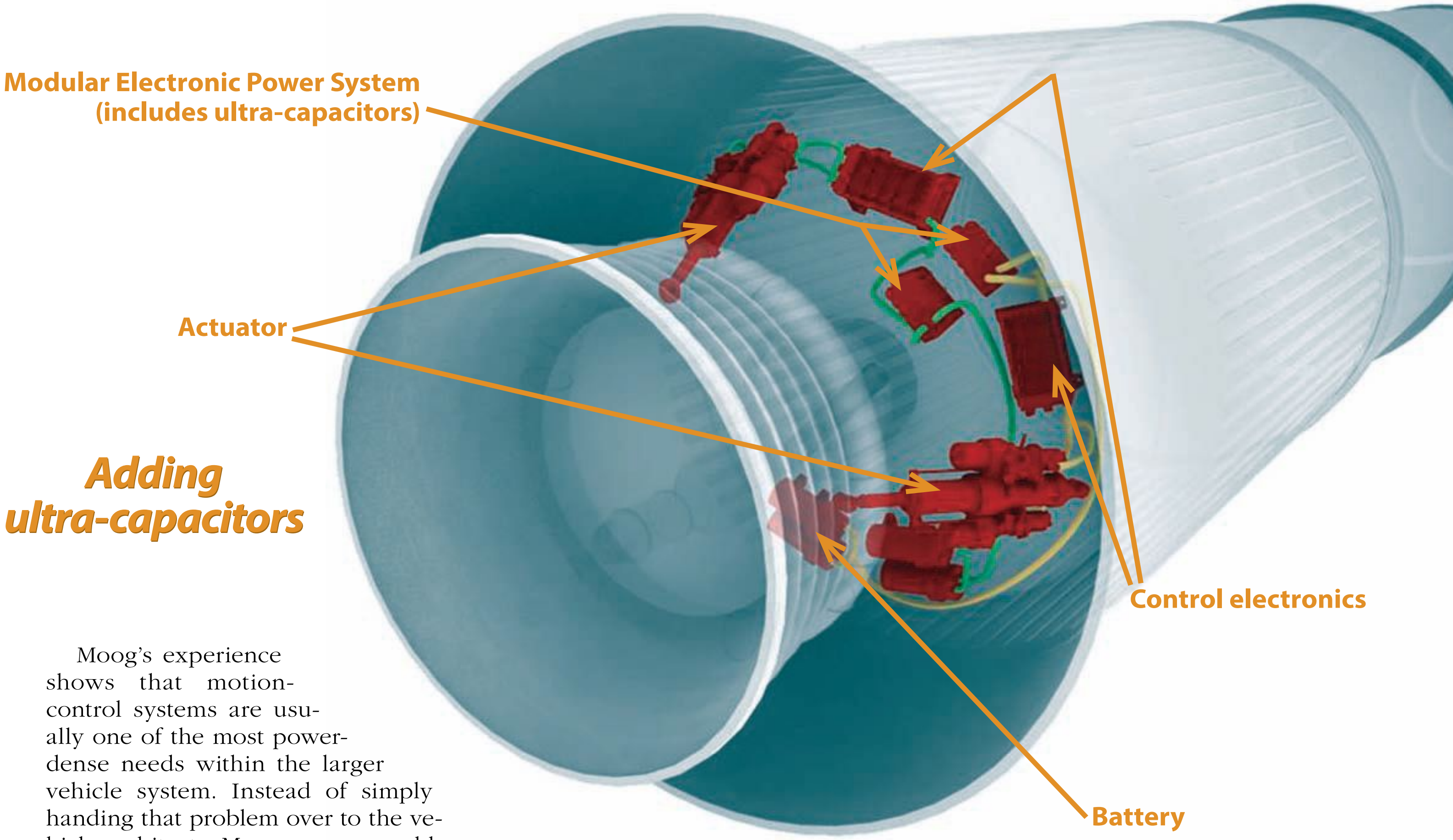
Launch vehicle manufacturers are shifting from traditional hydraulic to new electrically driven motion-control solutions, including versions made by Moog. In these systems, motion arms, called actuators, push and pull on a rocket's nozzles to adjust the direction of thrust during flight. These adjustments are small but they require a large amount of electrical power for a few seconds. The shift toward electric thrust vector control systems has complicated matters for the power system architects who must determine how many batteries a launch vehicle will need to ensure peak power demands are met.

In early 2013, Moog set out to make life easier for system architects by replacing many of the lithium-ion batteries in their designs with ultra-capacitors like those used in the hybrid cars and buses. Ultra-capacitors are a form of double-layer capacitor that uses a nonsolid electrolyte; the separation of charge between electrode and electrolyte provides a means to electrostatically store and transfer energy. Ultra-capacitors act as electric accumulators, accepting current from a source or sources such as a stack of batteries, to deliver electricity to power consuming components. One could think of capacitors as short-term power boosters that are recharged after depletion.

Moog has performed ground tests with a prototype Modular Electric Power System, or MEPS, unit, and the results suggest applications for thrust vector control as well as in the aviation domain, for example to supply power to flight control surfaces of military and commercial aircraft.

Moog's concept calls for combining ultra-capacitors and lithium-ion batteries to form a hybrid system. While the immediate problem being addressed is the power-hungry nature of motion-control systems, we believe this technology will ultimately let system architects in many domains reimagine their design approaches.





Adding ultra-capacitors

Moog's experience shows that motion-control systems are usually one of the most power-dense needs within the larger vehicle system. Instead of simply handing that problem over to the vehicle architects, Moog proposes adding ultra-capacitors to increase the flexibility of the design, which would reduce the number of batteries that must be stacked or packaged together to meet the peak power needs. The weight savings could be as much as 30 percent compared with the power systems that today supply electricity to thrust vector control systems or flight surface control systems.

Currently, the MEPS ultra-capacitors are supplied to Moog by Ioxus of Oneonta, N.Y., which makes them for the transportation industry. The big breakthrough was devising circuitry robust enough to connect these ultra-capacitors to the batteries within a launch vehicle or other aerospace systems. If someone were to simply hook up an ultra-capacitor to a battery, there would be a large rush of current that would destroy the copper wire and circuitry over which the current must flow. Moog has developed a circuit that will maintain each ultra-capacitor in a zero voltage off state until there is a need. The circuitry then modulates the current to prevent overcharging and returns to a passive state for operation.

Moog's innovation does not stop with clever circuitry. Moog used the MEPS endeavor as an opportunity to apply additive manufacturing processes. First, a plastic version of the case for the first prototype was made, and then a titanium version was grown at the Moog additive manufacturing center in East Aurora, N.Y.

The big attraction of ultra-capacitors is that they have roughly an order of magnitude less internal impedance than batteries. This characteristic means that for the same amount of power going through a system, there is less heating within the individual cells that comprise the ultra-capacitor, and therefore a reduced thermal concern for designers. There is also a much greater regenerative energy capture potential because of the voltage flexibility of an ultra-capacitor. Architects using MEPS ultra-capacitors can remove the burn-off resistors in their design, which are necessary because not all energy regenerated by an aircraft's flight control surface, for example, can be directed back to its turbine generator or possibly a battery. This limitation exists as a result of the tight window of upper and lower voltages that designers must stay within when using batteries.

Another advantage for rocket designs is that an ultra-capacitor could be installed adjacent to the control box of its thrust vector control system. That's a lot different than today's architectures in which cables are run 10 or 20 feet from a centralized battery to the control box.

All told, with the use of ultra-capacitors, designers can use smaller, more optimized batteries, and smaller gauge wire between batteries and electrical control boxes. All of which adds to the weight and cost savings of replacing some batteries with ultra-capacitors.

The ultra-capacitors can be used in a centralized system in which the ultra-capacitor would be packaged with batteries, known as a MEPS hybrid module. A second architecture is a decentralized one in which the MEPS ultra-capacitors would be packaged separately from batteries, allowing direct connection to a central vehicle power system — the main wires and electronics running through a satellite, rocket or aircraft.

In either configuration, the MEPS

ultra-capacitors would provide a buffer action, similar to an accumulator, between those loads and the batteries or central vehicle power system. This approach decreases the load placed on the central vehicle power system. Thus, designers could downsize a lot of the components that connect all of the pieces together.

In a very dynamic load situation, think of the battery as a brick with a string and feather tied to it. The ultra-capacitor is the feather, and the blowing wind from a fan is like voltage: The feather's going to blow uncontrollably in response to the load. The battery (or directly connected vehicle power system) is still needed for voltage regulation, because the ultra-capacitor is just like a regular capacitor in the fact that it has limited energy storage capability. Without the battery, the feather simply blows away.

Moog has performed experiments on a thrust vector control inertial load simulator and exercised MEPS under loads in the 300-volt, 300-amp regime. Moog engineers are now in the process of qualifying the technology for flight on launch vehicles.

Rocket applications are just the beginning for MEPS. In the aviation domain, researchers are trying to migrate toward all-electric or electrically driven propulsion systems in addition to electrically controlled flight control surfaces. Moog proposes to insert the MEPS ultra-capacitors and use them as a buffer between the vehicle power system and the load to provide regenerative energy capture capability, as well as reduce the power burden on the vehicle power system. Military aircraft, for example, have a very high peak driven load because of their control surfaces. With the addition of ultra-capacitors, the vehicle power system, instead of being responsible for supplying hundreds of amps, now has a dramatically reduced requirement.

Our engineers have provided a solution for a technical challenge as well as afforded our customers a new level of system design flexibility.

Jonathan Kasper is the project engineer for the Modular Electric Power System research at Moog in East Aurora, N.Y. Greg Semrau is a system engineer at Moog. This article was adapted from a presentation delivered by Semrau at AIAA's Propulsion and Energy Forum in Cleveland in July.