Electronics poised to replace steam-powered aircraft launch system

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You have seen videos of aircraft launched from decks of naval carriers. In about 300 ft (100m), the aircraft must accelerate to its "wind-over-deck" takeoff speed of more than 100 knots (roughly, 1 knot=1.2 mi/hour=0.5m/sec) so that the aircraft can literally take flight as it reaches the end of the carrier deck. In the earliest days of aircraft carriers, some of the propeller-driven aircraft could take off unassisted if they were lightly loaded, but naval engineers soon realized that they would need a power-assist for most launches. The launch problem got more difficult as jet aircraft (which have higher takeoff speeds) and larger, heavier aircraft became common.

For more than 50 years, the steam-powered catapult has been the assist system designed into aircraft carriers to launch aircraft. (Engineers have also used solid-fuel rocket boosters attached to aircraft, but this technique carries some major disadvantages.) Although the steam-catapult system has worked well and is well understood, a new generation of Navy designs is striving to simultaneously meet goals of lower operating cost, reduced crew requirements, greater flexibility, and improved performance as the present system has been refined to its technical end and has some inherent limitations that are not likely to be overcome.

Electronics, smart power, and new electrical and mechanical devices are the key to an entirely different type of launch system. Using a LIM (linear induction motor) as the prime mover, these systems will be installed in a next-generation carrier, the CVNX-1, which should become operational around 2013. Based on research in the 1990s and preliminary contracts awarded in 1999, two prime contractors, Northrop Grumman and General Atomics, both teamed with numerous subcontractors, are independently developing demonstration systems and will compete for final contracts (Reference 1).

Why not just let off some steam?

The steam-driven piston-in-cylinder engine powered the industrial revolution that began in the mid-1800s and is still with us today. Almost any fuel can fire steam boilers, which can develop high pressures, and most important, the engines driven by steam pressure can provide enormous force at zero or low rpm, without complex transmissions. Due to the nature of the steam cylinder and internal piston, the engine's output motion and power can ramp from zero to maximum in a very short time period.

But steam has its drawbacks. Like so many engineering accomplishments, steam is simple in concept but becomes extremely complex in practice. Take a look at a late-generation steam-powered locomotive with its thousands of subassemblies, such as valves, condensers, radiators, coils, pipes, and fittings. Steam systems require considerable and constant maintenance; for example, hydraulic fluid and leaking oil cover every moving part. They are also relatively inefficient and are large and heavy. In aircraft carriers, the systems use a significant amount of valuable below-deck space, and much of their weight is topside, where it affects the ship's stability and righting ability. The system's low efficiency of about 5% is also a drawback.

Steam systems have two other major limitations for the future. They have reached their practical limit of operating and launch energy for their allocated space, at approximately 95 to 100 MJ. Yet aircraft are getting heavier, and some need even higher takeoff speeds than current systems offer. Also, they are open-loop systems, so you can't control their output power and acceleration profile. Therefore, they can overstress the aircraft with over-rapid acceleration or transients during the launch sequence, thus contributing to a need for more frequent airframe inspection and maintenance, as well as shortened aircraft-service life due to material fatigue.

Power electronics offers new approach

The Navy's EMALS (Electromagnetic Aircraft Launch System) represents a radically new approach to the launch problem. Although based on the LIM, which is a well-established technology, this application requires enormous impulse power and energy, unlike other LIM applications (Table 1). The complete EMALS system will use a 300-ft long LIM to accelerate a 100,000-lb (45,000-kg) aircraft to more than 130 knots (67m/sec) and lighter aircraft to 200 knots (100m/sec). The system consists of four elements (Reference 2, Figure 1): an energy-storage subsystem, which takes its power from available ship power sources and accumulates it; a power-conversion subsystem, which takes the stored energy and converts it into high-impulse, controlled energy output to drive the LIM; the LIM itself, which is the launch motor; and control consoles, which allow operators to set launch parameters and monitor the entire system.

As an additional benefit, the EMALS will allow closed-loop control over the launch profile, reducing launch stress and providing tighter control on launch performance. Note that as a form of launch insurance, the open-loop, roughly calibrated steam system is now set to give more power than is absolutely necessary; this extra power is additional airframe stress.

Although many designers worry about milliwatts and microamps, the EMALS project requires the delivery of substantial amounts of power and energy precisely during the 2- to 3-sec launch release (Reference 3). Thermal issues are not a matter of dissipating just a few watts; instead, they involve megawatts of heat that must be managed and dissipated with every 45-sec launch cycle. In addition, severe shock and vibration, a truly hostile environment, and maintenance access are design issues.

The energy-storage subsystem uses rotors of a disk alternator as a flywheel to kinetically store energy it draws from the ship's power system. Each rotor will store more than 100 MJ, spinning at more than 6000 rpm. Ship electric power drives the rotors to their target rpm, and then the power-correction subsystem uses the same coils that drive the rotor to draw off their power as the rotor shifts from its motor mode to its alternator mode. The rotors operate in a vacuum chamber to eliminate air drag and increase efficiency; their output is approximately 80 MW each at maximum speed. Even at the anticipated efficiency of about 90%, there is about 100 kW of heat that the system still must remove from the alternator, and this is done via several heat-transfer subsystems.

At launch, the power stored in the rotor is released through a cycloconverter, which is a controllable source of rising frequency and voltage for the linear launch motor. Each LIM comprises a row of stator coils that pull a carriage (equivalent to a conventional motor's rotor) as long as these coils are energized via very-high-power SCRs (silicon-controlled rectifiers). To minimize losses and provide maximum available power at the location of the shuttle, only the section of the stator that surrounds the vicinity of the shuttle is energized at a particular time. SatCon Technology Corp, a subcontractor to General Atomics, is providing the design and manufacture of the Block Switch Assemblies that provide this function; several hundred such assemblies will be required per ship. These SCRs are about the size of a dinner plate, measure about 10 cm thick, and handle tens of thousand of amps at several thousand volts. The several hundred stator coils are energized in carefully controlled succession to pull the carriage and thus the aircraft forward via a tow bar.

The applied power is controlled through a closed loop so that the actual launch profile is matched to the requirements of a particular aircraft load and to overall system-performance variations; the design uses Hall-effect sensors to determine the position of the carriage along the motor rail. The magnetic flux strength in the LIM gap is about 1 tesla.

Even though brushless commutated motors are relatively efficient, they are part of a very-hig--power system, and the losses result in significant heat dissipation in the stator, on the order of 10 MW. Active cooling, including fluid flow around the switching elements and their mounts, is necessary to get the heat energy away from the system. The SCRs are mounted on sophisticated railing assemblies that play a critical part of the thermal-management strategy and also allow ship personnel to remove and replace individual SCR-module subsystems.

The potential benefits of EMALS go beyond improved and tighter performance, reduced personnel, simpler maintenance, flexibility for different manned and unmanned launch loads, less stress on aircraft, and about half the weight and volume of the steam catapult. EMALS is compatible with the all-electric ship that the Navy is striving towards, which will have greater flexibility in control, routing, and use of power as well as much better operational oversight. Further, to replace the hydraulic system used now, the EMALS design may lead next to an electric-based aircraft-arresting system used on landing and will have similar benefits.

References

1. Erwin, Sandra, "Navy to phase out steam catapults on carriers," *National Defense*, www.nationaldefensemagazine.org/article.cfm?Id=539.
2. "Electromagnetic Aircraft Launch System (EMALS)," www.ga.com/atg/emals/emals.html.
3. Samuel, Douglas, Thomas Conway, and Robert Klimowski, "Electromagnetic Aircraft Launch System-EMALS," 1994, www.lakehurst.navy.mil/nlweb/ieeerevc.pdf.