

A Small LightningStrike

By Mike Hirschberg , Executive Director

As described in the last issue of *Vertiflite* (“Lightning Strikes Aurora”), after four-and-a-half years of development, the US Defense Advanced Research Projects Agency (DARPA) awarded Aurora Flight Sciences an \$89.4M contract to develop, build and flight test its VTOL X-Plane. Aurora’s LightningStrike uses a distributed hybrid-electric propulsion system: a Rolls-Royce AE 1107C turboshaft (the same T406 engine as used in the V-22 Osprey) drives three Honeywell 1 MW (1,340 hp) generators through a gearbox (more than 10 kA — enough to power a home subdivision); the generators in turn power 24 electric motors, driving constant speed, variable pitch fans (18 on the wing and six on the canards). Both the wing and canard tilt for vertical takeoff and landing.

The full-scale X-Plane is designed to weigh 12,000 lb (5.4 t) with a 40% useful load. The program completed the 22-month Phase 1 with a preliminary design review (PDR) in Sept. 2015. The contract award covers 21-month detail design, fabrication and ground test in Phase 2, followed by a nine-month flight testing Phase 3.

Big Ideas

The LightningStrike program seeks to develop a vertical take-off and landing demonstrator aircraft that will achieve a top sustained flight speed of 300-400 kt (555-740 km/h), with 60-75% increase in hover efficiency over existing VTOL aircraft. Aurora’s design is for the first aircraft in aviation history to demonstrate distributed hybrid-electric propulsion using an innovative synchronous electric-drive system. Having successfully completed the subscale demonstrator flight, Aurora’s LightningStrike team will focus over the next year on further validation of flight control system and configuration of the full scale VTOL X-Plane demonstrator.

The DARPA technology demonstrator’s flight control system (FCS) builds on the heritage of Aurora’s Centaur and Orion optionally manned and unmanned aircraft platforms. The FCS system runs on a triplex-redundant design to ensure detection and



Aurora’s LightningStrike subscale vehicle demonstrator (SVD) made its first flight on March 29 at Naval Air Station Patuxent River, Maryland. (All photos by Aurora)

correction of flight anomalies in both vertical and forward flight.

Pending successful completion of key program milestones to be achieved in close collaboration with DARPA, Aurora plans to conduct the first flight tests of the technology demonstrator in the 2018 timeframe.

Subscale Vehicle Demonstrator

The company built a subscale vehicle demonstrator (SVD) that had been readied for flight testing last September at Naval Air Station Patuxent River, Maryland, but it was decided to delay the testing until Phase 2 began. That aircraft made its first flight on March 29.

The subscale SVD aircraft weighs 325 lb (147 kg) and is a 20%-scale flight model of the full-scale demonstrator that Aurora will build over the next two years. The SVD wing and canard utilize a hybrid structure of carbon fiber and 3D-printed fused deposition modeling (FDM) plastics to achieve highly complex structural and aerodynamic surfaces with minimal weight. The unmanned aircraft take-off, hover and landing was controlled by Aurora personnel located in a nearby ground control station with oversight and coordination by US government officials, including DARPA personnel.

“The successful subscale aircraft

flight was an important and exciting step for Aurora and our customer,” said Tom Clancy, Aurora’s chief technology officer. “Our design’s distributed electric propulsion system involves breaking new ground with a flight control system requiring a complex set of control effectors. This first flight is an important, initial confirmation that both the flight controls and aerodynamic design are aligning with our design predictions.”

Although the SVD is battery powered (and not hybrid electric) and uses variable speed off-the-shelf fans, the dynamics and control allocations are essentially the same as the full-scale LightningStrike. Aurora says that the demonstrator has validated the aerodynamics, vehicle configuration, avionics, software, CFD and flight controls (which are 80% common with the full-scale aircraft); in fact, the fly-by-wire system flown is a single string of the triplex-system planned for the large demonstrator.

LightningStrike Systems

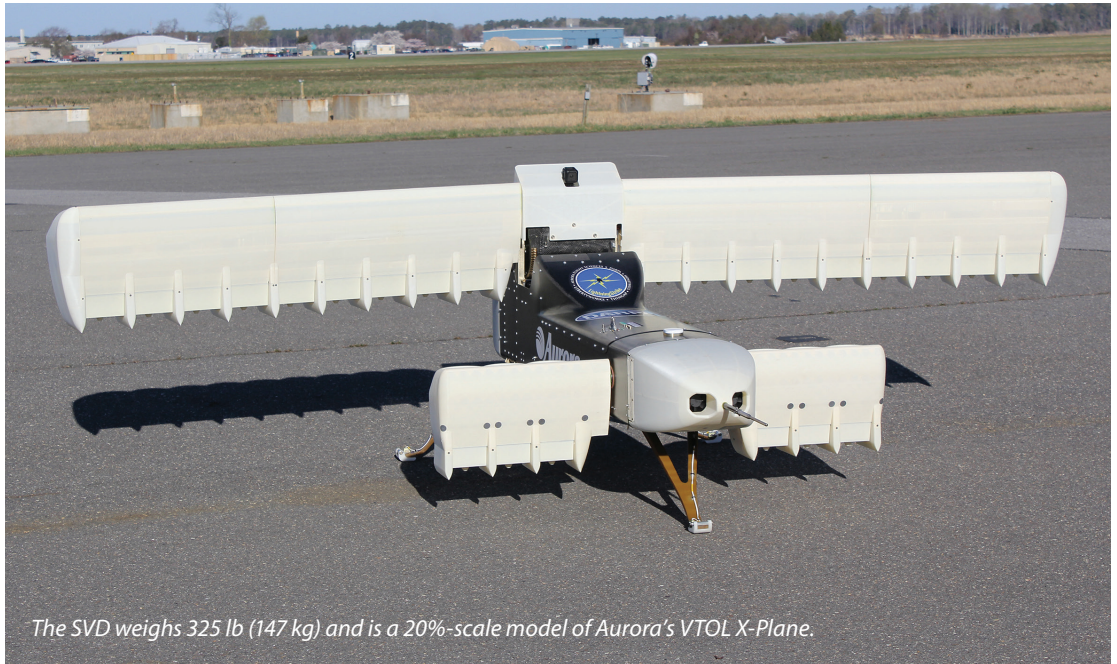
Honeywell recently tested a 19,000 rpm 1 MW wound-field generator that weighed 279 lb (126.5 kg) — about 350 lb (160 kg) for the system, including the generator control unit and the rectifier bridge and filter — with a length of 24 inches (61 cm) and a diameter of 14 inches (36 cm).

The motors are built by ThinGap, a privately owned motor design and manufacturing facility located in Ventura, California. The wings use 100 kW motors, while the canard motors are 70 kW each. The motors do not use motor controllers; rather, LightningStrike uses an AC-coupled system, eliminating nearly 1,000 lb (450 kg) of controller weight.

Rolls-Royce LibertyWorks is designing and building the power generation system, including the driveshaft and gearbox. The engine FADEC is from the US Navy's Ship-to-Shore Connector (SSC) hovercrafts built by Textron, which also use the Rolls-Royce AE1107C turboshaft engine (designated MT7 for the gas turbine installation). The full-scale aircraft will be able to carry 3,000 lb (1.4 t) of fuel, divided in two fuel bays. Aurora is developing the engine inlet, while the main and nose landing gear are from the Sikorsky S-76.

The avionics system draws major elements from Aurora's prior programs. In addition to the ground control station for the company's Centaur optionally piloted aircraft, the triplex-redundant integrated flight system and the dual-redundant mission-management computers are from Aurora's Orion unmanned aircraft, which made a world endurance record flight of 80 hours in 2014. This approach allowed significant software reuse from prior Aurora programs.

The LightningStrike control system is over-actuated, with 74 primary effectors available for flight control: including



The SVD weighs 325 lb (147 kg) and is a 20%-scale model of Aurora's VTOL X-Plane.

variable pitch on each of the 24 fans, eight sets of ailerons (on the wings) and four elevons (on the canards), as well as independent tilt actuators for the wing and canard (which can actuate over a total of 94° of tilt). The aircraft is expected to convert between fan-borne and wing-borne at 80-100 kt (150-185 km/h).

Progress and Plans

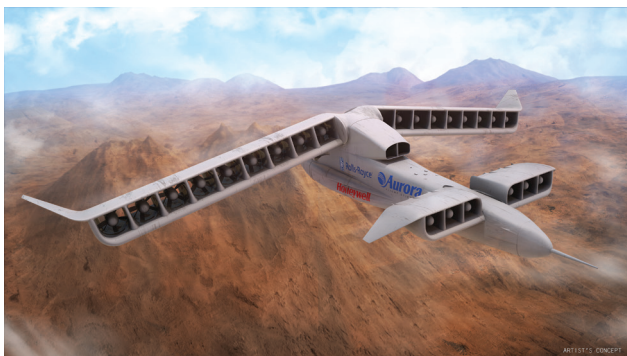
During Phase 1, Aurora used its high performance computing cluster to generate computational fluid dynamics (CFD) modeling of the full LightningStrike aircraft initial configuration. Phase 1 wind tunnel testing included three entries between April 2014 and Oct. 2014; this comprised powered canard testing, a powered wing section and a powered sub-scale aircraft half-model. In parallel, Aurora completed wind tunnel/CFD correlation, including force and moments, and the full aerodynamics database.

During Phase 1 of the program, Aurora designed and tested the full-scale, five-bladed variable-pitch fan. The company also performed risk reduction with a test rig dubbed the "Copper bird," which verified the full-scale motors, fans and control mechanics.

Over the next 12 months, Aurora plans to continue flying its SVD to validate the control

laws and control allocation. The company will conduct a Critical Design Review (CDR) and Manufacturing Readiness Review (MRR). Honeywell will conduct a full-power test of the 1 MW generator planned for flight, while Rolls-Royce will complete the (custom) gearbox fabrication and load testing early 2017. Tooling will arrive late this summer/early fall to allow the start of component fabrication.

Design and fabrication of a Hardware-in-the-Loop Simulator has recently begun. An iron bird is being designed to test the entire power generation system and electric distribution system — everything from the AE1107 engine to the variable pitch fans. The test rig will begin evaluation at LibertyWorks in Indianapolis, Indiana, and then integrated into the full-scale aircraft. The full-scale LightningStrike VTOL X-Plane will begin ground testing, followed by flight testing in mid-2018.



The 12,000 lb (5.4 t) LightningStrike uses a unique hybrid distributed electric propulsion system with 24 variable-pitch fans.

Carl Schaefer, Program Manager of Aurora's VTOL X-Plane Program, provided exceptional insights into the LightningStrike project at Forum 72 in the Transformative Vertical Flight Special Session. Presentations are available on the Forum 72 Special Session CD or in the Vertical Flight Technical Library in the AHS Online Store: www.vtol.org/store.