

# Compound Interesting

Even without flying a Joint Multi-Role Technology Demonstrator, AVX Aircraft advances its Coaxial Compound Helicopter solution to Future Vertical Lift requirements.

By Frank Colucci

**A**VX Aircraft Company did not stop work on its Coaxial Compound Helicopter (CCH) when the US Army chose big industry teams to build and fly Joint Multi-Role (JMR) Technology Demonstrators. Under a continuing Technology Investment Agreement (TIA), the small engineering house in Benbrook, Texas, is refining CCH aerodynamics and plans to test a 1/10-scale model of its Future Vertical Lift (FVL) concept in the 7-by-10 ft (2-by-3 m) low-speed wind tunnel at Texas A&M University in January. AVX is also working with Continuum Dynamics, Inc. (CDI) in Ewing, New Jersey, and Advanced Rotorcraft Technology (ART) in Sunnyvale, California, to model CCH performance and handling. Still to be funded is a contract option for a notional half-scale CCH model for testing in the National Full-Scale Aerodynamics Complex (NFAC) at Ames Research Center, California, in early 2018. "We're in the process of setting up an IPT [Integrated Product Team] to look at this," explained AVX president and chief engineer Troy Gaffey. "There will be people from AVX, ART, CDI, as well as the government working for several months defining what the test would be."

JMR schedules call for the Bell Valor tiltrotor and Sikorsky Boeing Defiant compound helicopter to fly in 2017. However, the Army Aviation and Missile Research, Development and

*AVX Aircraft continues work on the Coaxial Compound Helicopter as part of the Joint Multi-Role Science and Technology program. The current configuration has revised canards and fan ducts to optimize lift and reduce drag. (AVX)*

Engineering Center remains clear that JMR Technology Demonstrators are not prototypes for an FVL Program of Record. The Science and Technology (S&T) initiative aims to mature tools and skills needed to design, analyze, predict and evaluate scalable next-generation rotorcraft for the many missions of the US armed services. AVX declined to give its CCH a bold tradename, leaving possible future choice to the Army. "We are not working with either Boeing Sikorsky [sic] or Bell," noted Gaffey. "We are, in fact, under contract in a competitive phase of the program."

AVX was one of four company/teams signed to JMR TIAs in October 2013. (See "Joint Multi-Role Moves Forward," *Vertiflite* Jan/Feb 2014). It proposed a full-sized Model Performance Specification aircraft and a three-quarter-scale demonstrator, both with stacked coaxial rotors, ducted fans and lifting canards to achieve higher speed and greater range than conventional helicopters. "We delivered several things," said Gaffey, "the biggest was a complete design of the aircraft." The package included manufacturing and cost reports. "It was a pretty comprehensive description of what we planned to do, both for the full-scale

aircraft to replace the Black Hawk and Apache and our demonstrator."

Bigger than a Black Hawk, the Mission Performance Specification vehicle sized for four crew and 12 troops had a mission weight of 28,000 lb (13 t) and a rotor system 56 ft (17 m) in diameter. Even the 16,000 lb (7.3 t) demonstrator would have had 42 ft (13 m) diameter rotors. "It was a pretty good-sized aircraft," noted Gaffey. "It was powered by two [Y]T706 engines... really the CT7 engines in the Sikorsky S-92. That should give you an idea of the size." The CCH has counter-rotating coaxial rotors to harness lifting power typically wasted on anti-torque rotors. Fixed forward canard surfaces and a horizontal tail with ducted fans generate lift at high speeds. The differential fans also provide directional control, and their protective ducts augment thrust at low airspeeds and increase fan efficiency in cruise.

AVX evolved its coaxial concept from the type used on comparatively slow but efficient-lifting Kamov helicopters. In the compound configuration with auxiliary thrusters, the coaxial rotors are used mainly for lift and not for forward thrust. Rotor hub controls are simplified and vibration reduced to increase speed. AVX analyses so far show sails

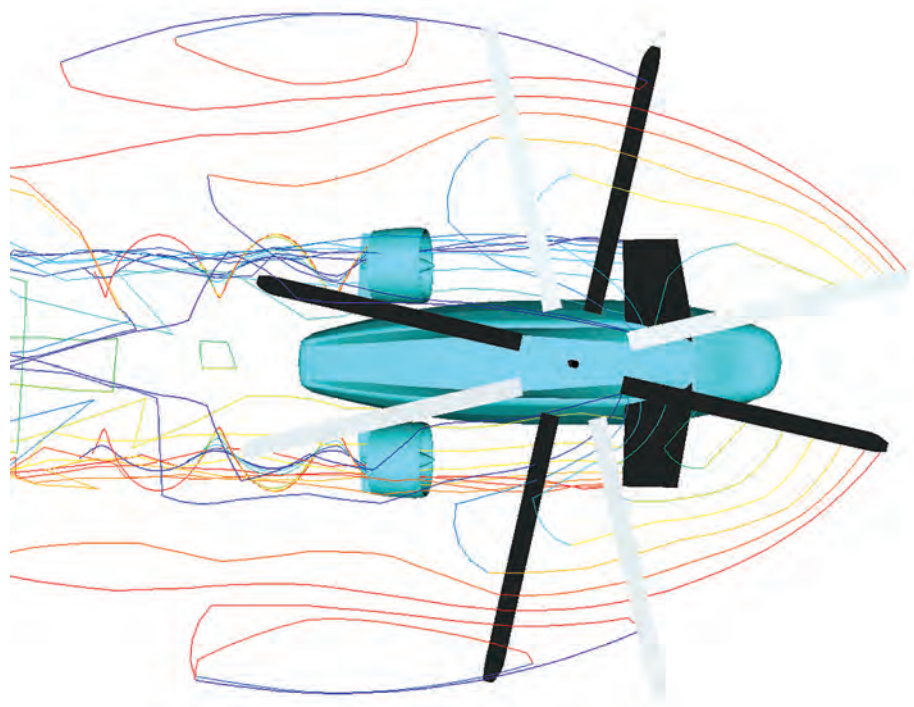
and other rotor hub treatments offer no significant drag reduction, and that a coaxial rotor system less rigid than that of the Sikorsky Boeing Defiant promises the CCH a better empty weight fraction. "Our modeling has consistently shown, in my opinion, that we're on the right track," said Gaffey. "We certainly discovered things, and we changed the design as we went along... We have made detail design changes to the canard, small changes in the location of the canard and more tapering to reduce drag."

The original AVX dihedral tail has meanwhile straightened, and the thruster ducts now have less chord. "Actually, our duct arrangement now looks like the nacelle on a 737 airliner, under the wing," observed Gaffey. "One of the things we're trying to do in our wind tunnel test is fix a few aerodynamic characteristics we didn't like and reduce drag. If you can reduce the drag, you can go faster with less horsepower and in general get more range out of the aircraft." The JMR Mission Performance Specification calls for 230 kt (430 km/h) cruise speed and 2,100 nm (3,900 km) ferry range without refueling. (See "Paying For Speed," *Vertiflite*, May/June 2014.)

After an Initial Design and Risk Review (IDRR) was held for each of the JMR four teams in June 2014, the Army downselected Bell and Sikorsky Boeing to build their JMR Technology Demonstrators. The broader JMR S&T program nevertheless continues to fund work by Karem Aircraft and AVX on their respective Optimum Speed TiltRotor and CCH solutions. "We are under contract to the Army as well. That started this spring," said Gaffey. "That contract was directed at refining our Coaxial Compound Helicopter configuration. It consists of a great deal of analysis and some wind tunnel tests." A second task continues AVX work with Continuum Dynamics, Inc. According to Gaffey, "The guys there are very knowledgeable in rotorcraft, and they're going to be doing CFD [Computational Fluid Dynamics] modeling of the aircraft. They will be looking at the interaction between the main rotor downwash and the body of the aircraft, including the ducted fans."

## Model Builders

Contract researcher Continuum Dynamics, Inc. (CDI) has long licensed its CHARM (Comprehensive Hierarchical Aeromechanics Rotorcraft Model)



*Continuum Dynamics, Inc. is using its CHARM modeling tool to help AVX optimize CCH main rotor airfoils and twist and ducted propeller aerodynamics. This image shows one of the earlier CCH variants modeled. (CDI)*

software to Sikorsky, Boeing and other US rotorcraft makers and Department of Defense laboratories. "We don't always hear from our customers what they're doing with CHARM," acknowledged CDI senior associate Dr. Todd Quackenbush. CDI began working with AVX in the JMR Configuration and Trades Analysis (CTA) phase in 2011, and CHARM modeling provided raw data on CCH rotor and ducted propeller performance, rotor aerodynamic loads and airframe loads for the trade studies.

Given AVX design guidelines on rotor size, blade count and tip speed, CHARM analysis helped determine main rotor airfoils and twist, and ducted propeller aerodynamics. Quackenbush offered, "The feedback we provide AVX is 'old school' in the sense that, for example, AVX specifies a particular arrangement of the canard and stabilizer or a range of incidence angles for those surfaces, and we report back what CHARM says about the forces and moments they generate."

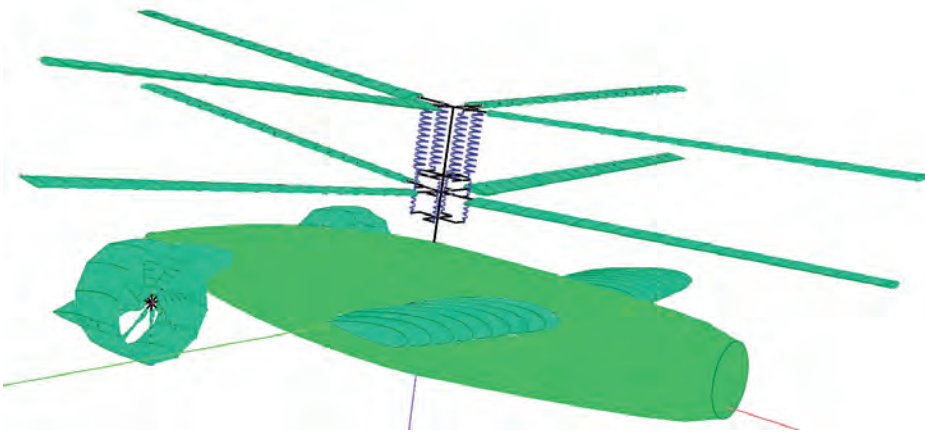
CDI worked closely with AVX rotor and fan blade fabricators Eagle Technologies in Newport News, Virginia, and Rotating Composites in Kensington, Connecticut, to make sure CCH aerodynamic designs were compatible with structural and manufacturing requirements. CDI also provided supporting information ranging from studies of rotor out-wash around the aircraft in ground effect to full

performance maps for piloted CCH flight simulations.

The key advantage of the CHARM tool is its ability to assemble fully interactive aerodynamic models of all the elements in complex rotorcraft, such as the CCH. According to Quackenbush, "The different parts of the model feed each other directly. As opposed to the fixed-wing world where correction factor is piled on correction factor... everything is talking to everything else at the same time. That's something you have to do with helicopters as opposed to the fixed-wing world."

The interactive CCH model combines models of two coaxial main rotors, two ducted propellers and a lifting panel including the fuselage, ducts, canards and stabilizers. Given initial design parameters, CHARM models rotorcraft performance, blade loading, Blade Vortex Interaction (BVI) noise, flow fields and hub loads. "The good thing is you can put all these calculations together, and they can run on fairly simple laptop computers in an hour to two hours," said Quackenbush. "We even have versions in real-time flight sims."

CDI uses its Cartesian Grid Euler (CGE) solver to cross-check CHARM analyses and solve special problems such as hover download calculations. The model builder also draws on industry-standard Reynolds Average Navier-Stokes Equations (RANS) CFD



Advanced Rotorcraft Technology is using its Rotorcraft Comprehensive Analysis System (RCAS) to explore CCH rotor dynamics and vertical spacing between the upper and lower rotors. Image shows the RCAS Model Viewer representation of the AVX CCH aircraft. (ART)

models to address specific problems. CDI will use AVX wind-tunnel data to refine its computer models. According to Quackenbush, "Flow-back from the wind tunnel data is always important, of course. We have a good track record with predicting rotor performance and full configuration aerodynamics for a wide range of airframes. However, even though we start with a good deal of confidence in the model, for a novel configuration like CCH with many interactive elements, doing successive validation efforts as we get more and more wind tunnel data over time will be important."

### How Does it Fly?

A third JMR contract task calls for AVX to examine CCH dynamics and flying qualities in early 2016. Advanced Rotorcraft Technology, Inc. (ART) supported CCH design and analysis in the JMR IDRR phase and continues the work today. The simulator software maker

is using its Rotorcraft Comprehensive Analysis System (RCAS) to explore CCH rotor dynamics and vertical spacing between the upper and lower rotors. RCAS is a joint development of ART and the Army's Aeroflightdynamics Directorate (AFDD) at Ames Research Center. The comprehensive multi-disciplinary rotorcraft simulation code uses a hierarchical, flexible multi-body dynamics formulation to model complex rotorcraft. The analysis will support CCH control law development to mitigate rotor clearance issues and hub vibratory forces and moments.

ART is also using its commercial FLIGHTLAB modeling, analysis and real-time simulation development tool to evaluate aerodynamic interactions between the CCH rotor, airframe and thrusters. The results are used to check control laws that are being developed to mitigate rotor dynamic issues, as well as provide handling qualities that comply with the ADS-33 specification. ART is using its in-house simulator with the

FLIGHTLAB model to run real-time CCH simulations for piloted evaluations.

ART will use the recently-developed viscous Vortex Particle Method (VPM) to analyze CCH rotor wake interactions between the upper and lower rotors, the airframe and the ducted fans. The robust, computationally-efficient VPM solves vortex wake-dominated problems for complicated aircraft. It can be coupled with either a lifting line-based blade element or lifting-surface model, such as FLIGHTLAB, or a grid-based RANS CFD solver, such as OVERFLOW or FUN3D. In the coupled solution, the FLIGHTLAB model or the CFD solver computes the vorticity source from body surfaces while VPM transports the wake vorticity throughout the flow-field.

ART President Dr. Ronald Du Val summarized, "Both FLIGHTLAB and RCAS use physical parameters provided by the manufacturer to model the rotorcraft. These include the geometry of the rotor blades and retention system, mass and finite element elastic properties, aerodynamic tables of the airfoils used for the blades and other aerodynamic control surfaces, tables of six force and moment coefficients as a function of angle-of-attack and sideslip for the fuselage, control system block diagrams, transmission geometry, and tables of turboshaft engine thermodynamic properties. FLIGHTLAB, RCAS and VPM can all be interfaced to CFD codes as an alternative to using data tables for the airloads. All of these parameters can be varied to modify performance, loads, handling qualities, etc., as required."

Detailed modeling could help build the half-scale CCH-JMR model AVX Aircraft hopes to test in the NFAC wind tunnel. AVX patented the Coaxial Compound Helicopter configuration around 2008 and is already working

with an unspecified government agency on another CCH application. According to Troy Gaffey, "The government has acknowledged that we have limited rights to the design of the dynamic components, the main rotor and the drive system. That's because we've invested our own money in that."



AVX conducted small-scale wind tunnel tests at the National Institute for Aviation Research (NIAR) at Wichita State University. A 1/10th-scale model will run in the low-speed tunnel at Texas A&M early in 2016 under the JMR contract with the Army. (AVX)

