Build Them and You Will Learn

Bell V-280 tiltrotor design reflects V-22 lessons, Army requirements

By Richard Whittle

Fixed engines on the V-280 Valor facilitate sliding side doors for rapid egress. (Bell Helicopter)

Bell Helicopter's new V-280 Valor tiltrotor troop transport, like most offspring, bears a strong resemblance to its immediate forebear — in this case, the V-22 Osprey. The V-280 — the first two versions of which are being built for the Army-led Joint Multi-Role Technology Demonstrator program — is much smaller than the V-22, sized to carry 11 to 14 troops rather than the Osprey's maximum 24. With a targeted cruise speed of 280 kt (520 km/h) or higher, the Valor is also faster than the Osprey, which cruises at 250 kt (460 km/h).

The Valor differs from the Osprey in other important ways as well. For starters, the Valor's two engines will be fixed horizontally on its wingtips — unlike the Osprey, whose engines are housed with its rotors in wingtip nacelles. As a result, troops can get in and out of the Valor through side doors rather than a rear ramp like the Osprey.

The 35 ft (10.7 m) diameter of the V-280's proprotors is nearly as great as the V-22's 38-ft (11.6 m) diameter rotors, but the Valor's maximum weight for the JMR demonstration is 38,000 lb (17.2 t) for a rolling takeoff — a good deal less than the Osprey's maximum 52,600 lb (23.6 t). As a result, the V-280's disk loading — pounds of thrust per square foot of rotor disk area — is about two-thirds the Osprey's. The V-280's wing is also straight and level, and has a higher aspect ratio than the Osprey's, which sweeps forward and has dihedral (i.e. it is angled upward).

Bell is using a "tail-dragger" landing gear configuration on the V-280 — two pairs of wheels forward and one smaller pair under the tail — rather than the V-22's "tricycle" landing gear, which consists of two pairs of wheels under the aft cabin and one pair under the Osprey's nose. In addition, the Valor sports an upward V-shaped tail rather than the Osprey's H-tail.

Vince Tobin, Bell vice president for advanced tiltrotor systems and leader of the V-280 design team, said major design changes in the Valor compared to the Osprey "fall into two categories: those that are based on what we learned from the V-22 — just the differences in the decades that have passed in technological development — and then also from the [Army's] pure [JMR] capabilities requirements differences."

Designed in the early 1980s and built by Bell in a 50-50 partnership with The Boeing Company, the Osprey became operational in 2007. Bell's 1950s-era XV-3 Convertiplane, whose large, single engine was inside the fuselage, and the 1970s XV-15 technology demonstrator, whose two engines were housed — like the Osprey's — in tilting wingtip nacelles that also held its rotors, preceded the V-22. But the Osprey is the first tiltrotor put into production. The Marine Corps has been flying Ospreys operationally for eight years and the Air Force Special Operations Command for six, providing a wealth of "lessons learned."

"We built the V-22 a long time ago," said Tom Wood, now chief technologist at Bell and whose work on tiltrotors began in the 1960s. "We didn't know everything we know today."

Fixed Engines

Among those lessons are the disadvantages caused by rotating the V-22's two Rolls-Royce AE1107C Liberty (T406) engines. After landing in helicopter mode, Osprey pilots have to remember to shift the nacelle position at intervals to prevent the hot engine exhaust from burning ship decks or starting grass fires. The latter hazard led to the loss of at least three Ospreys in the aircraft's early operational years. Others were damaged by fires caused by hydraulic fluid from the V-22's Engine Air Particle Separators dripping into the engines when the nacelles rotated upward. Those problems have largely been solved by training and mechanical changes. But tilting the V-22's engines upward has also increased their tendency to ingest damaging and dangerous amounts of dust, dirt, and sand on takeoff and landing.

Despite all that, Tobin said avoiding such problems wasn't what initially drove Bell to fix the V-280's engines in place. That decision, he said, was driven by a desire to give the Army a familiar way of getting troops into and out of the Valor.

"The Army has been coming out of its medium lift aircraft out of side doors since 1965 [and] our assessment, with the help of a consultant, was that they would probably want to continue to do that," Tobin said. "Obviously, you can't come out the side door and run into an engine that's coming down to within a foot or two of the ground in helicopter mode, so we needed to eliminate that. So what that drove was having to fix the engines and come up with a methodology to rotate only the rotor."

The JMR demonstrator version of the V-280 will use General Electric T64-GE-419 engines, derived from those used on Sikorsky's CH-53E helicopter. One result of fixing the engines on the wingtips rather than swiveling nacelles is that a gaping hole in the wing facing forward opens up beneath the V-280's nacelles when they rotate upward. Wood said this space above what he calls "the cradle" of the nacelle creates no significant drag because the aircraft is in helicopter mode when the nacelle tilts up, but Bell engineers considered trying to close the hole to prevent dust and dirt from entering the nacelle there. Wood and Tobin said they decided instead to live with what they regard as a minimal risk.

"It's not something we necessarily like, but it's a problem that's difficult to solve, it's hard to avoid," Tobin said. "Because when you're rotating a structure that large, it's difficult to figure out how to cover up that hole that it's left." Tobin said airflow around the hole should prevent excessive ingestion of dust, dirt or sand through that opening. "One thing you have to realize," Wood said, "is that as you move inboard next to the nacelle, the rotor wake is reduced at that point. The flow around the nacelle is much reduced from the velocity that's out there on the rotor where it's producing a lot of lift. The velocity varies as a function of rotor radius. You get inboard, that velocity value goes way down. In the XV-15 history, we tried a lot of different variable things to cover up stuff, but the truth of the matter was, it never paid [its] way onto the airplane." The same is the case with the gap under the V-280's upward-tilted nacelles, he said.

Making the V-280's engines stationary was a design challenge for Bell engineers, Tobin said, for it required "coming up with a methodology to rotate only the rotor." At first, some engineers resisted, because the design that connects the V-22's proprotor gearbox and tilt-axis gearbox had to be replaced with "a completely different package." Wood added that putting side doors under the V-280's wing meant "we had to work really diligently to come up with a good design solution, because it softens the fuselage right under the wing, where you really would like it to be stiff."

The result, Tobin said, is that troops exiting a V-280 will have "an 8-foot [2.4 m] clearance under the wing for field of fire and… unfettered ability to egress out of side doors and establish a perimeter." The potential reduction in the hazards experienced with the V-22's tilting engines "are all great benefits," Tobin said, "but the impetus was to come out side doors."

V-280 Proprotor Size, Straight Wing Differ from Osprey

Benefits also should flow from using proprotors nearly the size of the Osprey's for an aircraft just over half as heavy. But again, Tobin and

Bell is completing the V-280 fuselage in Amarillo, Texas, on the V-22 assembly line. (Bell Helicopter)

The latest V-280 mock-up shows the current configuration with a reduced-area V-tail and nacelle "cradle." (AHS International)

Wood said that requirements set by the customer, rather than lessons learned from the Osprey, were the motivation for that difference.

When the Osprey was designed in the early 1980s, the primary customer was the Marine Corps. The Marines wanted a cabin the size of a CH-46 Sea Knight troop transport helicopter — big enough to carry 24 troops loaded for combat — but also wanted the Osprey to operate from Tarawa-class amphibious assault ships. Required to taxi past the superstructure of such ships with its rotors no less than 12 feet 8 inches (3.9 m) away from the "island" and its outboard tires at least five feet inboard from the edge of the deck, the V-22's proprotors could be no more than 38 ft (12 m) in diameter — about five feet less than ideal for an aircraft that size, according to engineers working on the project at the time. That gave the Osprey extremely high disk loading and literally hurricane-force downwash. The smaller V-280, with proprotors nearly as large as the Osprey's, will have disk loading of about 15 to 16 lb/ft^2, roughly one-third less than the V-22, and should produce at least 20% less downwash velocity.

Another visible difference is the V-280's straight and level wing, which Wood said pays a host of dividends compared to the V-22's dihedral, forward-swept wing. For starters, Wood said, going to a straight wing "allowed me to get a higher aspect ratio wing, which helps my lift-to-drag ratio and my efficiency aerodynamically." The straight wing also greatly simplified the mechanisms needed to connect the rotors with a driveshaft to keep them coordinated and, in case of an engine failure, both rotating. That, in turn, eliminated the need for a mid-wing gearbox, a device that adds 292 lb (132 kg) to the Osprey's weight and expense to its price.

The Osprey's wing was swept forward out of caution based on what was known about the complex aerodynamics of tiltrotors when the V-22 was designed, Tobin said. "When we built the V-22, we weren't exactly sure what the rotor flapping was going to be in forward flight," Tobin explained. "To accommodate that, we put forward sweep in the wings to make sure that when that inboard blade flapped backwards that it wasn't going to contact the wing. What we've learned is that, in forward flight, tiltrotors do not flap significantly… We had more margin that we probably needed with the wing sweep."

Straightening the wing offers a clear example of how Bell's engineers have worked to reduce the cost and complexity that give the Osprey's critics fodder and its fans occasional heartburn. "When you put dihedral and sweep in there, you get some complex angles that you have to address with your driveshafts that go from rotor to rotor to keep the interconnect working, so if we straightened out the wing, we've simplified the manufacturing process significantly," Wood said. "You just cannot believe how it simplified the manufacturing process of the wing."

Tail-Dragger Landing Gear, V-Tail Offer Advantages

Another design change driven both by the culture of the customer and lessons learned from the V-22 is the choice of "tail-dragger" landing gear for the V-280, with two pairs of large wheels under the nose and a single pair beneath the tail, which reverses the arrangement of the Osprey's "tricycle" landing gear. The Army's UH-60 Black Hawk and AH-64 Apache helicopters use tail-dragger gear, Tobin noted, and with no rear ramp on the V-280 to preclude such a configuration, Bell decided to follow suit. But using tail-dragger configuration also responds to a V-22 lesson learned: nose-gear failures during landings on unimproved surfaces have damaged Ospreys often enough that the Marines have imposed a 5 kt (9 km/h) limit on forward speed when their V-22s land on unimproved surfaces. The V-280's tail-dragger gear should allow faster landing speeds in unimproved areas.

Another V-280 design change — the choice of a V-tail instead of an H-tail, like the Osprey's — was made for multiple reasons. Wood recalled that the V-22's designers went with an H-tail because a V-tail would have been too tall to fit under the deck of an amphibious assault ship, requiring hinges so it could fold. Bell's engineers had no need to meet shipboard storage requirements for the Army, but beyond that, Tobin said, the V-tail "provides the opportunity to reduce aircraft signature, potentially enhancing its military capability. It also has the potential to

The larger ratio of proprotor diameter to fuselage weight results in Valor disk loading that is only two-thirds that of the V-22 Osprey. (Bell Helicopter)

mitigate co-site issues associated with antenna placement on the aircraft as compared with the H-tail. Finally, with the advanced fly-by-wire flight control system, the V-tail provides the opportunity to develop improved control surfaces, with the potential to improve handling and reduce weight."

Building a Better Future

Spirit AeroSystems delivered the fuselage for the first of two V-280 demonstrators to Bell Helicopter's Amarillo, Texas facility in early October, with installs currently underway. As of early December, Bell's JMR team had completed the wing box closure, with the upper and lower composite wing skins attached to the wing box. This is significant because it is a bonded wing, meaning very few fasteners, while the wing skins are "paste bonded" using just pressure at ambient temperature and no autoclave. Bell is also completing the engine nacelle builds.

The company's Systems Integration Lab (SIL) recently integrated the Flight Control Computer (FCC) Cross-Channel Data link (CCDL), which enables all three computers to communicate, a critical function in the tilrotor's triplex FCC architecture. The Valor's next major software build will be released early in 2016.

With the first V-280 demonstrator rapidly being completed, wind tunnel and other testing now done, flight controls hardware and software coming together, and first flight scheduled for September 2017, Tobin and his team are confident of the V-280's future well beyond the aircraft's JMR Technology Demonstrator phase. Bell is already designing a naval/Marine Corps variant (see *Vertiflite* Nov-Dec 2015) with folding proprotor blades and a wing-stow mechanism — features that will add weight and cost, but permit the V-280 to both land and "live" on ships larger than DDG destroyers, which are too small for the aircraft.

"We have a design solution we believe in," Wood said. "We've done some analysis on this and we're actually building an airplane. We'll find out when we fly if there are any issues that we have not been able to foresee."

About the Author

Richard Whittle covered the Pentagon and other Washington beats for The Dallas Morning News for 22 years. He is the author of *The Dream Machine: The Untold History of the Notorious V-22 Osprey* (Simon & Schuster, 2010) and *Predator: The Secret Origins of The Drone Revolution* (Henry Holt and Company, 2014)