Bell has taken a low-risk, low-cost approach with its fairly conventional model 360 Invictus. (Bell graphic)

Future Vertical Lift — Fulfilling its Promise

After more than 10 years of effort, FVL is finally beginning to fulfill its promise of replacing all legacy US combat helicopters with next-generation rotorcraft.

By Mike Hirschberg, Executive Director

In 2008, at the urging of the Vertical Flight Society and its members, the US Congress directed the Department of Defense (DoD) to initiate a vertical lift joint program office and a "capabilities based assessment." The Pentagon responded with its proposed joint Future Vertical Lift (FVL) initiative and delivered its comprehensive FVL Strategic Plan to Congress in 2012, which laid out ambitious plans to recapitalize its entire rotorcraft fleet over the coming 30-40 years. (See our extensive FVL resource page for more information: **www.vtol.org/FVL**.)

Today, there are multiple lines of effort being undertaken by the US Army, Navy and Marine Corps, with significant participation by the US Air Force, Special Operations Command (SOCOM) and Coast Guard. Joint Service FVL "Capability Sets" range from CapSet 1 light manned scouts to CapSet 5 heavy lifters, and progress is being made in the first three size classes, as well as advanced unmanned aircraft (see "The Moving Parts of Future Vertical Lift," *Vertiflite*, Sept/Oct 2019).

The Army Joint Multi-Role Technology Demonstration (JMR TD) program has developed advanced vehicles and technologies to support the entire family of FVL aircraft. Since the greatest number of aircraft to be replaced (e.g. the Apache and Black Hawk) were in the medium class, the Army selected CapSet 3 (then known as FVL-Medium) — approximately 30,000 lb (13.6 metric tons) — as the approximate sizing point for the JMR demonstrators.

JMR TD set the stage for development of what will be the first two programs of record; the Future Attack Reconnaissance Aircraft (FARA), which corresponds to FVL CapSet 1 and the Future Long Range Assault Aircraft (FLRAA), which is the Army's version of FVL CapSet 3. The USMC has recently issued an RFI for their FVL CapSet 3 version, the Attack Utility Replacement Aircraft (AURA), running a few years behind FARA and FLRAA.

JMR/FLRAA Updates

In 2011, the Army funded configuration trade and analysis studies by AVX Aircraft, Bell Boeing, Boeing and Sikorsky. These were followed in 2013 by air vehicle development awards to AVX Aircraft, Bell, Karem Aircraft and Sikorsky-Boeing. The following year, Bell and Sikorsky-Boeing were selected to proceed to flight testing, while the efforts by Karem and AVX were refocused to demonstrate key technologies. (See "JMR Technology Demonstration Update: The Road to Future Vertical Lift," *Vertiflite*, Jan/Feb 2016.)

Bell was first to fly, with its V-280 Valor demonstrator taking off in December 2017. Today, the Valor has exceeded 300 kt (555 km/h) true airspeed and flown more than 130 hours, demonstrating low-speed agility. Bell is now gearing up to conduct autonomous flight testing.

The Sikorsky-Boeing team was delayed by manufacturing issues with its advanced rotor blades and its high-performance

The Sikorsky-Boeing team has installed the rotor fairings on its SB>1 Defiant demonstrator to reach speeds approaching 250 kt. (Sikorsky photo) gearbox. The team's SB>1 Defiant first flew this past March. At the Association of the United States Army (AUSA) Annual Meeting in October, Sikorsky-Boeing discussed their progress to date.

Ken Eland, Boeing's JMR-TD Program Manager explained that testing on the Defiant's Propulsion System Test Bed (PSTB) was being used to clear the aircraft for flight, with a total of 48 hours of run time, up to helicopter maximum speeds. After each modification of the design, the team demands twice as many ground test hours as flight hours put on the demonstrator. After a teardown of the PSTB this past spring, the team uncovered an issue in a transmission joint with "bearing creep" — excessive wear caused by slippage. Eland said that this is not all that uncommon but was unexpected after only a few hours of testing; he commented that common design rules for this phenomenon don't extend to the size of the Defiant transmission. Boeing used lessons learned from Sikorsky's CH-53K and expertise from academia to change the design. The components were redesigned and retested in the PSTB without the issue reoccurring.

Eland explained that the aircraft had completed four flights for a total of three hours: three flights in March-April, and the fourth flight on Sept. 24. The five-month hiatus was due to the bearing redesign prompted by the PSTB testing.

Flights of up to 20 kt (37 km/h) have now been conducted in all directions (fore, aft, left and right). The next flight, planned for October, is expected to double the speeds; then each flight will test to a new maximum speed in 40 kt (74 km/hr) increments. The aircraft has active vibration control, and Eland said it has only needed about 75% of its capability to keep vibration levels below that of the UH-60 Black Hawk.

Looking forward, Sikorsky-Boeing expects to fly beyond 100 kt (185 km/h) by the end of the year, barring any additional unforeseen issues. The Defiant's propulsor will be engaged early next year and hit the Army's 230 kt (424 km/r) required cruise speed by the end of March. The team plans to continue expanding the envelope up to its top speed (V_H) of around 250 kt (463 km/h), accruing about 115 flight hours in the process.

Boeing's Randy Rotte noted that the team could have kept flying before the bearings were a real danger, but they decided it would save time later in reaching V_H by pausing the flight test program over the summer for the fix. "Do we do a quick Band-Aid fix that'll get us to the next [test] point, or do we do a more longer-term adjustment that supports [the overall goal of reaching V_H]? So far, we've been taking that longer-term view," he said. "Whatever the design ends up being for FLRAA, all these things that we've learned will now be designed-in…."

Eland elaborated that they made a "slight design modification to better control that joint … so that it didn't become a potential safety of flight issue."

Eland also highlighted the team's testing in the Defense Department's National Full-scale Aerodynamics Complex (NFAC) wind tunnel at the NASA Ames Research Center. In June, Sikorsky-Boeing completed their second round of testing of a one-fifth-scale model of Defiant up to its planned maximum speed of 250 kt.

Sikorsky JMR program manager Jay Macklin explained that the team is now preparing for the FLRAA Concept Demo and Risk Reduction (CDRR) phase. The team submitted their proposal a day prior to the Oct. 1 deadline. The Army plans to make two contract awards by the end of February for the 18-month study phase. Macklin noted that the Defiant team now has six years of data and lessons learned that will be applied to their FLRAA design. In addition, depending on what the final requirements are for the Army's FLRAA and the Marines' AURA, the aircraft may need to be slightly larger than the JMR demonstrator, he said.

Karem's 36-ft diameter, single-rotor tiedown testing is now underway to demonstrate the company's suite of optimum speed tiltrotor (OSTR) technologies. (Karem photo)

"We're following our really robust design process for testing," Macklin said. "We have a system integration lab [SIL], wind tunnel testing, we're utilizing the PSTB and we have the aircraft flying. All of those things are feeding information into this process for what will actually come out as the [FLRAA/AURA] design."

As noted, AVX Aircraft and Karem Aircraft were also funded for JMR studies and demonstrations (partly with the additional funds that Congress provided to the Army — see "Washington Report," pg. 8). AVX conducted subscale wind tunnel testing of its Compound Coaxial Helicopter (CCH), while Karem built a full-scale rotor, nacelle and test stand for its optimum speed tiltrotor (OSTR) concept. Karem's 36-ft (11-m) diameter, single-rotor tiedown (SRT) testing is now underway at the company's test site in Victorville, California. The testing will demonstrate Karem's suite of proposed OSTR technologies.

FARA Comes into Focus

Requirements laid out by the Army for FARA last year included a maximum rotor diameter of 40 ft (12 m) to allow maneuvering in the "urban canyon" of cities in future conflicts, a maximum length of 46.5 ft (17.2 m), a maximum gross weight of 14,000 lb (6,350 kg), and a minimum cruise speed of 180 kt (343 km/h). The government also specified the planned 3,000 shp (2,240 kW) General Electric T901 Improved Turbine Engine (ITE), the ability to hover out of ground effect (HOGE) at 4,000 ft (1,200 m) and 95°F (32°F), a 20 mm cannon, the ability to integrate the Army's current and future weapons, air-launched effects (ALE), and the Army's Modular Open Systems Architecture (MOSA).

Five companies were awarded other transactions authority (OTA) contractual agreements in April for the FARA Competitive Prototype (CP) phase. A downselect of the five competitors is planned for this coming March. The two companies selected must

The AVX/L3Harris FARA full-scale mockup showed provisions for two troop seats on either side of the aircraft. (VFS staff photo)

have their "competitive prototypes" flying by November 2022, with the final winning aircraft design reaching initial operational capability in 2028.

AVX Aircraft unveiled their CCH concept for FARA in April, essentially a smaller, tailored version of their JMR TD concept. Now teamed with L3Harris Technologies, AVX has the horsepower to make a compelling bid for FARA, as exemplified by their full-scale mock-up at the AUSA meeting.

For high-speed flight, a pair of ducted propellers provide thrust augmentation, while small wings partially offload the coaxial rotors. Maximum speed is predicted to be 200 kt (370 km/h) or more.

The mock-up showed a weapons pylon on the right side, while the left side had seats for two SOCOM soldiers.

Bell unveiled its 360 Invictus conventional helicopter ahead of the AUSA convention, on Oct. 2. Stressing that the design meets or exceeds all threshold requirements laid out in the FARA contract — including a 185 kt (342 km/hr) cruise speed — Bell highlighted its low-risk, low-cost approach.

"Bell is committed to providing the US Army with the most affordable, most sustainable, least complex, and lowest risk solution among the potential FARA configurations, while meeting all requirements," said Keith Flail, Bell's vice president of Advanced Vertical Lift Systems.

The Invictus is a tandem-seat helicopter with a lift-sharing wing to offload the rotor in forward flight — this enables the higher speeds and high-speed maneuverability. Although it does not use a rear propulsor, it requires a Supplemental Power Unit (SPU) turbine engine to augment the T901, providing increased performance during peak power demand.

Bell said that the four-bladed articulated main rotor — with high flapping capability to enable high-speed flight — is based on the company's much larger five-bladed 525 Relentless rotor system, which has been tested at speeds above 200 knots (370 km/hr) true air speed.

Invictus (and doubtlessly all FVL aircraft) will leverage a fly-by-wire flight control system, which reduces pilot workload and facilitates autonomous flight. The 360 will be provisioned for enhanced situational awareness and sensor technologies, Bell stated in their press release, and the aircraft's MOSA approach is enabled by a digital backbone from Collins Aerospace.

Bell calculates that the aircraft will have a combat radius of 135 nm (250 km), including more than 90 minutes of time on station. It is designed to carry 1,400 lb (635 kg) of payload internally, to minimize drag and maximize range and survivability. Unlike the three other FARA designs that have been revealed so far, Bell is not designing their aircraft to carry troops due to the narrow fuselage that facilitates a lower drag configuration.

The company announced that the Invictus is a "Robust design integrating [the] lifecycle supportability processes early to ensure high [operations tempo] OPTEMPO availability in multi-domain operations," and uses "Design-as-built manufacturing model and digital thread enabled tools to enhance affordability, reliability, and training throughout the lifecycle of the aircraft."

Boeing announced at AUSA that it would not be revealing its concept to the public, but industry experts speculate that it is likely a winged-compound helicopter that leverages the company's design studies and wind tunnel testing of a lift-and-thrust-augmented Apache Compound (see "Compound Interest: Boeing Details Compound Apache at Forum 75," *Vertiflite*, July/Aug 2019), as well as early studies for JMR that instigated its teaming agreement with Sikorsky on the Defiant.

Bell's Invictus design has tandem seats and other attributes to minimize drag, facilitating a top speed of 185 kt without thrust augmentation. (Bell graphic)

Bell brought a full-scale mockup of the Invictus concept to the AUSA expo in October. (VFS staff photo)

Karem's AR40 active-rotor, winged compound design for FARA features a swiveling tail rotor thruster for both anti-torque and high-speed flight. (VFS staff photo)

Sikorsky's proposal for FARA is the Raider X, which is 27% heavier than its current S-97 Raider. (Sikorsky graphic)

Karem Aircraft revealed their active-rotor winged compound (ARWC) entry for the FARA competition at AUSA on Oct. 14. Dr. Thomas Berger, Karem's Director of Programs and FARA CP Program Manager explained that although the Army's 40-ft (12.2 m) width constraint effectively eliminated the tiltrotor as a potential solution for FARA, the advanced rotor technology developed for Karem's FLRAA OSTR is directly applicable to its FARA design. Karem has designated the aircraft the "AR40," indicating its 40-ft diameter active rotor.

The AR40 is a single-main-rotor, winged compound with a swiveling tailrotor. According to Berger, the aircraft is designed for speed and maneuverability, while maximizing mission utility, reliability and survivability. It has an optimum speed rotor (OSR) design that uses high-stiffness blades in a rigid hub, which eliminates the swashplate by using electromechanical actuators (EMAs) for individual blade control (IBC) for primary and higher harmonic control.

Attempts to eliminate the swashplate has been like a "Holy Grail" since the helicopter was invented. Replacing the swashplate on a rotorcraft with IBCs would bring numerous benefits — including reduced complexity, weight and drag — while providing the optimum blade pitch path trajectory for improved performance and reduced vibrations. Berger said that all of Karem's testing to date under the JMR TD program gives them great confidence in their ability to successfully use IBC on the AR40, dispense with a helicopter's swashplate for the first time in history.

The AR40 also features high-aspect wings to unload the rotor at higher speed, reducing the aircraft's drag and the power required by the rotor. The wings pivot independently: they tilt 90° to reduce download in hover, while in cruise they are used as part of the maneuver control system to optimize efficiency and control across the entire flight envelope. The inboard sections of the wing are fixed to avoid interference with the large weapon bay doors directly below.

Other drag reduction features include fairing the targeting sensor and stowing the 20 mm cannon when not needed. The low-profile rotor hub is faired and the wings are designed to offload the rotor even at moderate speeds.

Berger noted that the side-by-side seating for the pilots improves crew coordination. He also explained that the fuselage width and length provide additional space behind the cockpit to house four combat-loaded troops, making conversion to the SOCOM variant straightforward.

The AR40 carries all ordnance internally. The weapons bays are designed to accommodate the Army's Integrated Munitions Launcher but have additional capacity for future systems, such as the new Air Launched Effects (ALEs) that are under development.

Karem teamed with Northrop Grumman and Raytheon for the FARA CP program. Karem contributes the innovative and demonstrated rotor and drive technologies, while Northrop provides the full original equipment manufacturer (OEM) enterprise capabilities, including production and product support. Raytheon is the mission system integrator and MOSA architect. Berger said that although the Karem-Northrop-Raytheon team is a non-traditional rotorcraft team, they "bring the best of industry together to provide the Army with the best possible product for FARA."

Also at the AUSA Annual Meeting, Sikorsky unveiled its contender for the FARA CP. In the absence of any actual Army requirements, Sikorsky has been working on its 11,000-lb (5-t) S-97 Raider compound demonstrator since 2010. Originally designed to be a light tactical helicopter to replace the Army's OH-58D Kiowa Warrior, the FARA requirement, as noted above, was for an aircraft that is 27% heavier. Thus, Sikorsky has grown the S-97 into the Raider X, with the Raider's 36-ft (11-m) diameter rotor expanded 11% to the 40-ft (12.2-m) limit.

In the Raider X press release, Frank St. John, executive vice president of Lockheed Martin Rotary and Mission Systems (the business unit that Sikorsky falls under), stated, "RAIDER X converges everything we've learned in years of developing, testing and refining X2 Technology and delivers warfighters a dominant, survivable and intelligent system that will excel in tomorrow's battlespace where aviation overmatch is critical…. The X2 Technology family of aircraft is a low-risk solution and is scalable based on our customers' requirements."

Sikorsky sees the primary strengths of Raider X as being a high-performance air vehicle with room to grow: "The X2 rigid rotor provides increased performance including; highly responsive maneuverability, enhanced low-speed hover, off-axis hover [i.e. nose pointing], and level acceleration and braking," the press release stated. The speed engendered by the X2 advancing-blade concept will be well beyond the Army's requirements for FARA. This, and the company's digital design capabilities are expected to facilitate "rapid, affordable upgrades to stay ahead of the evolving threat."

Bell unveiled its FARA design on Oct. 2 at its Advanced Vertical Lift Center in Arlington, Virginia. These three models represent (left to right) the company's proposals for MUX, FARA and FLRAA. (VFS staff photo)

Sikorsky experimental test pilot Bill Fell highlighted the extensive testing conducted on the Raider: "Every flight we take in our S-97 Raider today reduces risk and optimizes our FARA prototype, Raider X."

The Plan Comes Together

The coming months will be incredibly exciting and have profound impacts on the future of military combat rotorcraft for the US and its allies.

FARA prototyping proposals are to be submitted in January, with the downselect to two competitors to be announced in March, as mentioned above.

In addition, as noted above, the proposals for the CDRR phase of the FLRAA acquisition program were due Oct. 1. Two teams will be selected for an effort that carries through fiscal 2021. In fiscal 2022, the Army plans a full-scale development award to a single company to build the Army's next-generation long-range assault aircraft, to be operation around 2030. The Army is designated as the lead service with SOCOM participation, and the Marine Corps acquisition program for AURA following about two years behind the Army.

Meanwhile, the Navy is starting to make headway with plans for its "FVL-Maritime Strike," CapSet 2, which will be its replacement for its Seahawk and Fire Scout missions. The Marine Corps has similarly been advancing its unmanned MUX program — "Marine Air-Ground Task Force (MAGTF) Unmanned Aircraft System (UAS) – Expeditionary" (see "Future Vertical Lift Takes Off," *Vertiflite*, July/August 2019) — in addition to its CapSet 3 AURA replacement of its UH-1Y Viper and AH-1Z Venom aircraft. There will likely be other synergies between these requirements and those of other services, such as Army's FARA, FLRAA and Advanced Unmanned Aircraft System (AUAS) programs.

The vision set out in the 2012 FVL Strategic Plan is finally coming into focus.

Dozens of additional FVL pictures from the AUSA Annual Meeting and Exhibition are posted in the VFS Photo Gallery: **www.gallery.vtol.org**. Check them out!