Making FVL

Following a digital thread, advanced manufacturing processes aim to make Future Vertical Lift affordable and sustain the enduring helicopter fleet.

By Frank Colucci

For the US Army, advanced manufacturing is key to the speed, range and cost goals of Future Vertical Lift (FVL), and promises to enhance readiness in the enduring helicopter fleet. Robotics, artificial intelligence, composite materials, additive manufacturing and smarter subtractive machining pay off with better performance, shorter lead times, lower costs and more competition. In October 2019, the Secretary of the Army directed advanced manufacturing be applied to new and fielded systems to support modernization and readiness. The Aviation and Missile Command (AMCOM) issued an advanced manufacturing policy memorandum for aircraft parts in March 2020 and will update the guidance with lessons learned from FVL and the enduring fleet. "The aviation payoff is the same as for the rest of the Army," said AMCOM Commander Maj. Gen. K. Todd Royar. "From an airworthiness perspective, we are first and foremost concerned about ensuring the safety and reliability of each part."

Royar is responsible for the Army's airworthiness authority but noted, "Advanced manufacturing is a team sport." AMCOM integrates its efforts with the rest of the Army Materiel Command (AMC), the Combat Capabilities Development Command (DEVCOM) Aviation and Missile Center (AvMC), industry partners and academic institutions. AMC's Corpus Christi Army Depot, for example, is investing in additive manufacturing and reverse engineering technologies to sustain the enduring fleet.

AMCOM has qualified an additive-manufactured antenna mount for Black Hawks and additive parts have repaired cracks in Black Hawks and Chinooks. Royar explained, "While a percentage of the parts will still likely be produced cheaper using traditional methods, many [additive] parts will likely be cheaper. This is especially the case for parts that are no longer in production and we only need a few."

Wichita State University and Sikorsky are building a UH-60L digital twin — an integrated 3D simulation — to help qualify parts made by advanced manufacturing processes (see "Twins After the Fact," *Vertiflite*, Nov/Dec 2020). The shared objective is viable, qualified parts that validate new airworthiness processes and ways to manage digital part data. Compared with paper drawings, 3D digital models can decrease time needed to get suppliers to produce parts and give the Army more potential suppliers. "Having a solid digital thread is critical to advanced manufacturing," noted Royar. "In order to ensure the quality and reliability of parts from an airworthiness standard, the integrity of the data is vital. How that data is stored, managed and utilized will define success or failure."

The four significant modernization efforts within FVL depend on advanced manufacturing to maximize performance and stay affordable (see "The Calculus of FVL," *Vertiflite*, July/Aug 2021). With weight, engine power and main rotor diameter set by the Army, the Future Attack Reconnaissance Aircraft (FARA) notably needs

The Bell Model 360 Invictus is one of two competitive prototypes to benefit from digital design and other advanced manufacturing technologies. The latest design changed the fantail to a conventional, high-mounted tail rotor. (Bell)

Proving It With Hardware

On Aug. 11, Bell released images of its 360 Invictus competitive prototype under construction, as well as operational images. The latest design changed the fantail to a conventional, high-mounted tail rotor.

Both the Bell 360 Invictus and the Sikorsky Raider X FARA competitive prototypes are about 50% complete. (Bell)

Since beginning the build in late 2020, Bell has made significant progress on the fuselage, main rotor blades, gearbox assembly, cases and other high-value components. The company said that "by implementing a design-as-built methodology that digitally connects the entire program throughout its lifecycle, Bell has increased its ability to collaborate in real-time with program partners and the Army. This method accelerates decision-making among distributed teams using a common, secure data environment that creates a singular source of data for the program leading to reduced assembly, rework time and cost."

Along with assembling the demonstrator, high-value components — such as the main rotor gearbox, driveshafts and couplings — are being tested at Bell's Drive Systems Test Lab (DSTL). The DSTL is used to carry out risk-reduction efforts that ensure the program has accurate and verified data to qualify components in advance of flight test. A new FARA-specific systems integration lab (SIL) is also operational at Bell. This facility allows the company to integrate flight-critical components, software, and mission systems for testing, verification, and validation of functionality before they take flight on an actual aircraft. This approach reduces technical risk and aids in the safe, rapid and efficient execution of flight test program.

Bell also announced it had retired its V-280 Valor JMR Technology Demonstrator after having made its last flight in June. "The V-280 Valor marked the completion of its three-year flight-test program with a series of demonstrations to highlight its revolutionary performance during more than 214 hours of flight," the company said. "The V-280 completed all planned Key Performance Parameters including low-speed agility, long-range cruise, 305 knot [565 km/h] high-speed flights, and rapid mission systems integration during this thorough test period." In addition, five Army experimental test pilots flew the V-280 over 15 sorties, and Bell hosted several "Soldier Touchpoint" events to gain useful feedback from pilots, mechanics and infantry squads for the Army program office to inform their requirements. "This feedback provided critical data that decreased risk and rapidly advanced the maturation of technology for a FLRAA weapons system to meet warfighters Joint All-Domain Operational requirements," Bell said.

Sikorsky and Boeing made the main gearbox of the SB>1 Defiant 25% lighter than historical projections, using advanced materials and 3D modeling. Here it demonstrates its external lift capability. (Sikorsky)

Meanwhile, Sikorsky and Boeing had not been as forthcoming with information about their competing designs, but continue to make strong progress with both the Sikorsky Raider X for FARA and the Sikorsky-Boeing SB>1 Defiant for FLRAA.

In July, the Defiant team announced that it had demonstrated "mission-relevant cargo capacity" by lifting a 5,300-lb (2,400-kg) Guided Multiple Launch Rocket System training load during a test flight at Sikorsky's Development Flight Center in West Palm Beach, Florida. "With DEFIANT X, the U.S. Army will deliver troops and cargo in future combat at twice the range of the current fleet," the news release said. The lifting power demonstrated by SB>1 Defiant demonstrator in this test equated to an Infantry Squad Vehicle, hundreds of thousands of rounds of ammunition, more than 600 gal (2,300 l) of water, or ~240 cases of Meals, Ready-To-Eat (MREs).

In May, the SB>1 Defiant demonstrator exceeded 230 kt (425 km/h) in level flight.

light, strong structures to achieve required speed and range. As of mid-August, the Sikorsky S-103 Raider X and Bell 360 Invictus competitive prototypes were more than 50% complete (see sidebar). The Program Executive Office (PEO) Aviation reports that the FARA program manager anticipates maximum use of advanced digital engineering and advanced manufacturing including model-based systems engineering, digital threads and digital twins.

Both FARA competitors have invested heavily in advanced manufacturing driven by digital engineering environments. The

The US Army Aviation and Missile Command has begun qualifying 3D printed aircraft parts like this wire bundle grommet. (US Army)

winner of the engineering and manufacturing development (EMD) contract in early fiscal 2024 should begin low-rate initial production around 2028. According to PEO Aviation, the model-based systems engineering framework started by AvMC early in FARA development is now fully coordinated across all FVL efforts and industry partners. The Future Long Range Assault Aircraft (FLRAA) request for proposals (RFP) was released in July and has Bell and the Sikorsky-Boeing team working on fully militarized designs of their V-280 Valor advanced tiltrotor and SB>1 Defiant advanced compound demonstrators, respectively.

FARA and FLRAA both prioritize speed and range and put new demands on rotorcraft structures and dynamics, and their missions cannot be done by cheaper unmanned systems. "Those two manned platforms are extremely important to our Army as we look at our modeling and simulation," said FVL Cross-Functional Team director Maj. Gen. Walter Rugen in a VFS webinar in August. "What Army Aviation gives us is a very low-latent decision process to F3EA — find, fix and finish, and then, importantly, exploit and analyze. Did we hit what we said we're going to hit? Did it have the effect that we wanted it to have?" He explained, "We don't see an AI [Artificial Intelligence] decision agent being able to do that in the 2030s. The soldier is still the best sensor. The solider sees in 3D. The soldier has the commander's intent, understands, is curious."

The Army intends to award an EMD contract for the FLRAA squad carrier in fiscal 2022, aimed at a first unit equipped (FUE) in fiscal 2030. An annex in the FLRAA RFP defines the Modular Open System Approach (MOSA) ultimately shared by FARA and the Future Unmanned Aircraft System (FUAS). Software and hardware standards shared across FVL platforms should enable the Army to add new capabilities without costly, time-consuming "vendor lock" on original equipment manufacturers (OEMs).

According to PEO Aviation, the model-based systems engineering framework helps the FVL programs define and facilitate MOSA. New-build FLRAA, FARA and FUAS platforms will share hardware and software defined by MOSA principles. The Aviation Mission Common Server (AMCS) puts open-system flexibility in the enduring fleet. In August, the first unit equipped with the digitized UH-60V Black Hawk introduced the first operational incarnation of MOSA. Northrop Grumman designed the government-owned UH-60V integrated avionics suite that can be updated by fourth-party suppliers. General Royar said, "Collectively we see having common standards across MOSA and AMCS will facilitate future advanced manufacturing processes for avionics."

Within the FVL FUAS modernization effort is a runway-independent Future Tactical UAS (FTUAS) to replace the cumbersome Shadow, and new, inexpensive Air Launched Effects (ALE). The Army in July asked for technical and cost proposals to look at ALE configurations, trade studies and analyses. In quantity, unmanned ALE will enable the manned FARA and FLRAA to confound enemy air defenses from safe stand-off distance. According to General Rugen, "We have to keep them cheap. We can't have boutique things. We want some mass there."

Mass Manufacturing

Bell is implementing advanced manufacturing on its Valor FLRAA and Invictus FARA contenders. The company unveiled its Manufacturing and Technology Center in Fort Worth, Texas, last August with experimental areas dedicated to composites, metals, additive manufacturing, assembly, automation and metrology. Bell VP of Rapid Prototyping and Manufacturing Innovation Glen Isbell noted each area fits an overriding strategy. "The simplify-improve-control strategy is kind of the core of most of what we do across all of these different areas… First, we look at the manufacturing process for a part, and then we try to understand how we can simplify that process… Everything I take out no longer causes me defects and I don't have to spend effort making better. We have to simplify."

After large-scale composite experience on the V-22 Osprey, the V-280 Valor Joint Multi-role (JMR) Technology Demonstrator gave Bell a chance to simplify, improve and better control tiltrotor manufacturing. "We pulled back and started the manufacturing phase of EMD three-plus years ago," said Isbell. "We started iterating on how I'm going to build the hardest parts." Proprotor blade spars topped the list. "We've been iterating with the design teams how to simplify the layup, the manufacturing of those parts, how to control the manufacturing process. We've built multiple spars, multiple parts, multiple skins and iterated with the design team over the last three years… A blade spar that took 16 shifts to lay up on the first prototype, we can now do eight times faster than that, and we haven't even automated it yet."

Better process control pays its own dividends. Isbell noted "Historically, our problems are found in composite parts after cure when it's too late to do anything about them… What we're trying to do is focus on the front end and drive a lot of data about the layup process so we can detect those things as they happen." The Valor demonstrator also tested thermoplastic composite ruddervators that eliminated fasteners to cut cost and weight compared with thermoset parts (see "Stamping Out Air Taxis," *Vertiflite*, May/June 2021). Isbell acknowledged, "We're evaluating thermoplastics. We're evaluating RTM [resin transfer molding]. A lot of it is, 'Can we simplify processes, and can we integrate with design?'"

The V-280 JMR Technology Demonstrator modeled a FLRAA with speed and range beyond conventional helicopters, and a tiltrotor with manufacturing technology more advanced than the V-22 (see "Getting Smart for FVL," *Vertiflite*, Sept/Oct 2017). The Competitive Development and Risk Reduction (CD&RR) Phase runs through May 2022 to the beginning of Engineering and Manufacturing

Development. Isbell said, "If we would have waited like the traditional OEMs do until they get on contract to start EMD, we'd go through only one iteration instead of a dozen... That is, we think, a strategic advantage for how we're going to build the FVL and how we're going to be able to do it at a significantly different price point per pound than has ever been done before."

Metal parts follow the same simplify-improve-control strategy. Isbell noted, "Our real focus is on complex drive system components and how can we make step-function changes in reducing both the cost and the cycle time of building parts." Bell gained materials and process knowledge applicable to both FARA and FLRAA from the Army Future Advanced Rotorcraft Drive System (FARDS) science and technology effort. The helicopter maker and materials engineering specialist QuesTek Innovations, LLC, evaluated Ferrium C64 secondary-hardening, fully martensitic steel gear to improve the performance and affordability of gears with reduced processing time.

The Bell Manufacturing Technology Center has its own gear production line to machine, heat-treat, carburize, grind and finish gears. Development work has cut set-up activities six-fold versus typical industry practice to reduce cost and errors. New inspection technology and process control validation also support adaptive machining. Isbell observed, "Today, if you find a quality problem in a batch, you have a problem with a whole bunch of parts. We've developed the capability to define that early-on and detect that part as it goes through."

The Bell 525 Relentless commercial helicopter was Bell's first application of the "digital thread" running through design, manufacture and support. "The V-280 is really the third or fourth generation of this kind of approach," said Isbell. "We do all of our assembles based on how the aircraft is actually being built, which gives us total transparency and visibility where parts are and the sequence of parts. We can identify problems and work those things through. Those also translate directly to the 3D work instructions that go to the shop floor."

Compound Construction

Conspicuously absent from recent Lockheed Martin FVL videos, advertising and web copy, Sikorsky Aircraft has implemented manufacturing technology on the Marine Corps CH-53K heavy lifter applicable to the Army-led FARA and FLRAA compound helicopters. The company notes the King Stallion was the first Sikorsky helicopter to benefit from an all-digital environment that stretches from design through production to sustainment. Digital design now enables CH-53K engineers to confirm designs meet specifications and mission requirements before production. It ties into tooling and fixtures on the production floor where, for example, digitally-enabled torque wrenches ensure quality — headset glasses show the user a green light when nuts are torqued properly and flash red if they are not. Digital work instructions also give CH-53K workers more efficient ways to perform tasks and reduce mistakes and rework. Sikorsky has begun trading digital design data with the King Stallion supplier base to eliminate delays in engineering changes.

For FVL, the digital thread can cut composite manufacturing costs by driving tools on the shop floor and maintaining data continuity with the engineering definition. Digital transformation initiatives have also enabled Sikorsky to condense development lead times on machined metal parts. The Raider X effort saw a 50% reduction in lead time for some machined parts versus other recent programs. Model-based manufacturing enabled the competitive prototyping team to start machining parts before design was complete, and simulation tools helped make the first machined piece flightworthy, eliminating the need for a manufacturing development example.

In one joint project with a supplier, Sikorsky has advanced from transmission frame block forging to titanium die forging so new parts arrive cut closer to their final form. The new process consumes 60% less raw titanium and takes 45% less time to machine the final part. Sikorsky is also creating tooling and production parts with additive manufacturing using high-strength polymer and 3D printed metal.

Sikorsky extends the digital thread to the manufacturing floor with digitally-enabled torque wrenches and glasses that show workers when nuts are torqued properly. (Sikorsky)

The rigid rotors on the Raider X FARA competitive prototype mix large cross-section blade roots with slender blade spars. Sikorsky engineers used a modular 3D-printed hybrid collapsible mandrel, 3D laser scanning, laser ply alignment and their digital thread to produce the complex shape quickly. Sikorsky and Boeing jointly developed an advanced coaxial main rotor gearbox for the SB>1 Defiant that used advanced aluminum alloys, thin-wall titanium rotor shafts, hybrid ceramic bearings, thermoplastic composite bearing cages, aluminum metal matrix bearing liners, and carbon composite and printed metal components to cut weight 25% versus predictions based on prior configurations.

For both FARA and FLRAA, Sikorsky plans to leverage the digital thread in assembly tasks, first simulating products, processes and factory operations to improve manufacturing. Automated torqueing, smart bonding meters and smart tools programed from digital work instructions will share the same digital thread. Automated guided vehicles will move parts and aircraft through final assembly and hangar operations.

Whatever the shape and origin of FVL, MOSA promises flexible systems readily updated without proprietary hardware and software from original system integrators. Open interfaces and government-use rights enabled the Collins Aerospace Common Avionics Architecture System (CAAS) developed for Special Operations helicopters to add functions and migrate to regular Army CH-47Fs, Coast Guard MH-60Ts and Presidential VH-60Ns. Collins, now part of Raytheon Technologies, was one player in the FVL Mission Systems Architecture Demonstration (MSAD) concluded last December. Results of the MSAD capstone exercise will shape the MOSA solution for FARA and FLRAA through the Army's architectural collaboration working group. Future architecture framework products go from the working group to

Honeywell Plans T55 Upgrade

Though Honeywell Aerospace will not comment on engine offerings for FLRAA, the company is continuing development of its 6,000-shp (4,500-kW) class T55-GA-714C upgrade for the CH-47F Chinook. The -714C upgrade centers on a state-of-the-art compression system for higher engine cycle pressure with greater efficiency and promises 22% more power and greater than 8% better specific fuel consumption than the 4,800-shp (3,600-kW) -714A version now in the CH-47F.

According to T.J. Pope, Honeywell senior director, military turboshaft engines, -714C compressor rig testing exceeded expectations, and design of the new engine is complete. Honeywell is buying and instrumenting engine hardware aimed at ground and CH-47F flight testing in 2022. Honeywell is partnering with the Army on a cooperative research and development agreement (CRADA) for the flight test program.

The T55-714C aims for a 25% improvement in overall engine reliability. According to Pope, "our design features a substantially reduced parts count, addresses leaks and other issues associated with the gearbox, and has features to improve erosion robustness in sand/dust environments. We kept the turbine temperatures low — below the melting point for sand — to assure robustness in sandy environments and long time on wing."

Performance and durability improvements are accomplished without expensive new alloys or exotic materials. Pope explained, "Our objective is to provide a significant improvement in power through an overhaul upgrade, for only slightly more than the cost of a normal overhaul, and to not compromise the T55's low sustainability cost." The proposed upgrade makes maintenance items more accessible with accessories relocated in a top-mounted gearbox.

Like the -714A engine, the -714C has dual-channel full authority digital engine control (FADEC). Minor FADEC changes accommodate the new compressor and associated control limits. Pope noted, "We carefully limited this scope for two important reasons: we wanted to keep the overhaul kit cost low, and we wanted to minimize the impact to the helicopter installation; both criteria help assure that these improvements can be incorporated affordably." To control cost and simplify aircraft integration, the upgraded Chinook engine has no new health and usage monitoring systems (HUMS) features.

In March, Honeywell received a follow-on Army contract for new-production and spare T55-GA-714A engines to support fielded aircraft and new CH-47F Block I production through 2024. The last three CH-47F Block I helicopters for the US Army will be delivered this year. The Block II CH-47F with high-lift rotor blades and drivetrain, fuel and electrical improvements remains in engineering and manufacturing development with production plans to be determined. Block II MH-47Gs in production for Army special operations aviation use the -714A engine.

The Army, Boeing and GE Aviation last year began tests of a Chinook (shown) with the GE T408 engine with the stated goal of risk reduction for a CH-47 with more powerful engines. With no program of record to develop and field a new 5,000–6,000-shp (3,730–4,475-kW) engine, the 30,000-lb (13.6-t)-class FLRAA Future Vertical Lift platform will also fly, at least initially, with a modified version of one of the currently available engines.

University of Wichita researchers are using scanning technology to make a 3D digital twin of the UH-60L Black Hawk for AMCOM. (US Army)

vendors as government-furnished information (GFI) to be incorporated into the aircraft.

Collins mixed foundational hardware and software in its next-generation MOSARC solution. The company has partnered with Bell on the Invictus FARA competitive prototype. Principal marketing manager for military avionics and helicopters T. Ryan Scoble explained, "MOSARC establishes a common set of key interfaces and content acceleration tools that enable rapid introduction of new technology and capabilities in the field, with defined boundaries between systems that need to evolve quickly compared with those that do not. This approach allows the customer the flexibility to compete and integrate the system with fourth-party mission capabilities with little or no effect on the safety-critical systems." Scoble added, "It also takes advantage of the technology and the pedigree of what has been developed with CAAS over the last two decades and modernizes its abilities, without completely abandoning all the DoD investments of the past."

How industry recovers its investments in MOSA capability is to be determined. PEO Aviation's Brig. Gen. Robert L. Barrie, Jr. told an Industry Day audience in August, "The key notion is [we] invest once in that capability and apply that across multiple platforms… The business case that we're asking industry to undertake is we want to acknowledge and appropriately resource and fund the work that has been done. What is different is, it's not in perpetuity for specific hardware or software. Instead, while that piece of technology is the best approach, we're going to use it, and when there's another evolutionary or revolutionary capability, we're able to employ that without breaking into the architecture of aircraft."

About the Author
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