The Power of FVL

Whatever the configurations of Future Vertical Lift, speed, range and availability depend on rugged new engines with higher horsepower, lower fuel consumption and diagnostic insights.

By Frank Colucci

The transformational speed and range of the US Army's Future Attack Reconnaissance Aircraft (FARA) and Future Long Range Assault Aircraft (FLRAA) depend in large part on powerful new turboshaft engines. FARA competitive prototype helicopters from Bell and Sikorsky will fly with a single General Electric T901 supplied as government-furnished equipment (GFE). The proposed FLRAA tiltrotor from Bell and compound helicopter from Sikorsky-Boeing are designed around twin Rolls-Royce AE 1107F and Honeywell HTS7500 engines, respectively, chosen by the airframers. All three powerplants promise more horsepower and better fuel consumption than today's technology. They also aim to move Future Vertical Lift (FVL) away from timed overhauls to on-condition maintenance.

With off-the-shelf engines, none of the fast FVL demonstrators flown so far are true FARA or FLRAA prototypes. The Army wants a 180-kt (333-km/h) FARA with a gross weight around 14,000 lb (6,350 kg). Until FARA competitive prototypes fly next year, Sikorsky's 11,400-lb (5,250-kg) S-97 coaxial compound helicopter plays 80% scale surrogate with a 2,638-shp General Electric YT706 turboshaft. The company-funded Raider, with its stacked rigid rotors and integrated tail propulsor, has achieved 207 kt (383 km/h) in cruising flight, demonstrated level acceleration and deceleration with its tail propeller engaged, and simulated combat maneuvers and emergency autorotations.

Two Army/industry-funded Joint Multi-Role Technology Demonstrators (JMR TDs) model a 30,000-lb (13.6-metric-ton) FLRAA. Over 214 flight hours, the Bell 280 Valor tiltrotor attained 305 kt (565 km/h) in level flight with two 4,500-shp General Electric T64s. At the end of flight testing, Bell engineers tore down the Valor proprotors and drive system to validate their advanced tiltrotor design and maintenance concepts. Bell FLRAA/V-280 vice president and program manager Ryan Ehinger explained, "We completed all JMR flight and ground-based testing, having validated that our models were effective and that our performance met our requirements." Eight hundred hours of ground testing in the Bell drive system test lab enabled the Valor to start envelope expansion after just 43 hours of restrained ground runs.

The compound coaxial Sikorsky-Boeing SB>1 Defiant achieved 247 kt (467 km/h) with two 5,000-shp Honeywell T55s, and continues to fly with 100 hours logged so far. As of March 29, the Defiant propulsion system testbed (PSTB) had accumulated another 234.1 hours, and the Defiant Team will continue testing both the PSTB and the flying demonstrator. Collectively, the team said, "As long as there is important data we can gather that informs the Program of Record, then we'll continue to operate."

The Defiant JMR TD with T55 engines flew 700 nm (1,300 km) from Florida to Tennessee. A production FLRAA would benefit from new engines with better fuel consumption. (Lockheed Martin)

Prototype Power

In March 2020, the Army narrowed the FARA "program of record" (meaning a formally approved and budgeted acquisition program) to Sikorsky and Bell, both working to design, build and test competitive prototypes (CPs). A single FARA engineering and manufacturing development (EMD) contract expected in early fiscal 2024 aims at low-rate initial production (LRIP) around 2028 and a first unit equipped (FUE) by 2030 (see "Risks and Rewards of FVL," *Vertiflite*, Nov/Dec 2021). Both FARA CPs are built around the 3,000-shp T901 engine, which is designed to pack 50% more power with 25% better fuel efficiency in the same size and weight as the Army's current GE T700.

The CPs use their power differently to achieve FARA speed and range. The Sikorsky Raider X is a compound helicopter that integrates coaxial rigid rotors with a tail propeller. In early April, it was about 85% complete at the Sikorsky development test center in West Palm Beach, Florida. The Bell Invictus CP with its articulated rotor, lifting wings and conventional tailrotor was likewise in work at the company's military aircraft assembly center in Amarillo, Texas; Bell similarly called Invictus 87% complete a few weeks earlier.

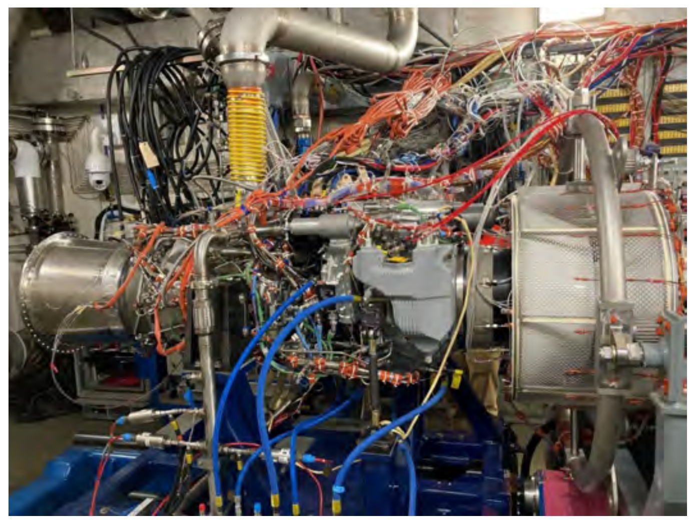
The single-spool T901 improved turbine engine (ITE) chosen by the Army to power the new armed scout will simultaneously revitalize the Black Hawks and Apaches of the Army's enduring fleet (see "Transition of Power," *Vertiflite*, March/April 2020). First flights in the Black Hawk and Apache are scheduled for fiscal year 2024. Ceramic matrix composites and other material advances from the GE commercial engine lines promise both better performance and longer time-on-wing than the T700 in today's Army helicopters.

GE completed ITE component and subsystem testing including the engine inlet particle separator and combustor in Lynn, Massachusetts, and Evendale, Ohio. The first light-off of the first engine to test (FETT) was on March 22 in a Lynn test cell, and the engine maker plans to run this fully instrumented XT901 for 100 hours over two months. According to the Army Program Executive Office for Aviation (PEO Aviation), ITE qualification testing will use seven XT901 engines plus one core engine (i.e., without the power turbine).

Preliminary flight rating (PFR) in late 2023 redesignates the engine YT901. The Army plans to use as many as 30 YT901s for platform integration and air and ground qualification testing. GE business development leader for advanced turboshaft engines Mike Sousa cited plans for 1,500 hours of full-scale ground testing to attain PFR and close to 5,000 test hours for full engine qualification. The Milestone C decision to end EMD and begin LRIP is expected between November 2024 and January 2025. The fully qualified engine becomes the T901-GE-900.

According to PEO Aviation, FARA plans call for six EMD prototype aircraft and two user evaluation aircraft. Eight more helicopters are planned in the first LRIP lot. Bell and

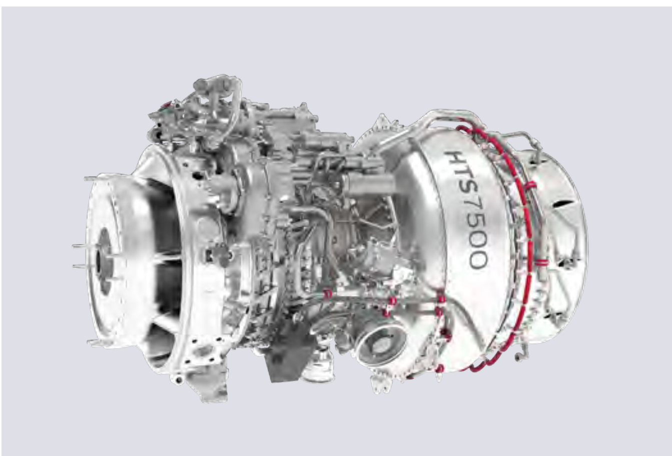
The Sikorsky Defiant X FARA competitive prototype is in assembly at West Palm Beach, Florida, and will fly with the Army's T901 improved turbine engine. (Lockheed Martin)



The XT901 improved turbine engine light-off at GE Lynn took place in March and promises both FARA competitors a powerful, efficient engine with integrated diagnostics. (GE)

A 3D-printed full-scale model of the GE T901 engine hangs from a sling in the Boeing Mesa facility during a mock-up fit check in an Apache helicopter. (Boeing)

The Bell V-280 Valor JMR TD models an advanced tiltrotor FLRAA with fixed engines for greater reliability and maintainability. (Bell)



The Honeywell HTS7500 leverages its T55 lineage and commercial engine technologies to give the Defiant X an on-condition engine for FLRAA requirements. (Honeywell)

Sikorsky will receive the first T901 flight test engines available — one engine each to support ground and flight tests in 2023. Two spare engines are also earmarked to support the CP efforts, and the Army continues to model the ITE and provide hardware for Bell and Sikorsky systems integration labs.

PEO Aviation noted that vendors in the FARA Competitive Prototype effort are required to complete drivetrain qualification tests prior to flight, but neither company is planning to build an "iron bird" or complete drivetrain ground test rig with the ITE. Jay Macklin, Sikorsky Army programs business development director, explained that Raider X drivetrain integration and qualification includes physics-based virtual prototypes, testing individual gear meshes, safety-of-flight component qualification, endurance tests and on-aircraft testing before flight.

FARA integration was added to the ITE EMD contract in 2019, and each fly-by-wire helicopter maker has collaborated on interface control documents with the engine developer. Sousa at GE explained, "The most significant integration effort relates to the control system and software that is unique to FARA applications." The company's T901 program director Tom Champion added, "We've worked closely with both FARA competitors to share critical information back and forth. From a GE standpoint we're ensuring both a physical model for fit checks, as well as digital models and data that will help prepare the engine for FARA integration."

Infrared exhaust suppression is not part of the T901 EMD contract, but GE assesses FARA engine interfaces and supports both competitors designing their survivable armed scouts. FARA is also meant to operate for extended periods without maintenance, and GE noted the T901 engine health management system draws on sensors, embedded models and algorithms to predict actual component lives and save spare parts and maintenance manhours.

Tilt Rotor Rewards

FLRAA is primarily a squad carrier meant to cruise around 230 kt (425 km/h) and cover a 229 nm (368 km) combat radius to cross a divisional area of operations twice as fast as today's helicopters (see "The Calculus of Future Vertical Lift," *Vertiflite*, July/Aug 2021). Bell and the Sikorsky-Boeing team are working under competitive demonstration and risk reduction (CDRR) agreements aiming at a single EMD contract this fiscal year.

Bell considers its V-280 Valor a third-generation tiltrotor, enhanced by lessons learned from the fast, long-range MV-22 Osprey. Like the Osprey, the Valor cruises on a fixed wing to double helicopter speed and range and tilts proprotors to decelerate quickly and maneuver at the objective landing zone. According to Rolls-Royce senior vice president Jena Wright, the Rolls-Royce AE 1107F engine chosen by Bell for FLRAA leverages a million flight hours of AE 1107C (T406) experience and an established supply chain from the V-22.

Rolls-Royce and Bell began collaborating more than four years ago on the Valor integrated propulsion system, from engine inlet to exhaust suppressor. The engine maker and airframer have completed testing inlet characteristics and compressor response. Rolls-Royce gives Bell an end-to-end FLRAA engine solution including an inlet barrier filter to improve the operational life of the powerplant.

Unlike the V-22 engines that tilt with their proprotor nacelles, the Valor keeps its engines horizontal in cruise and hover. Bell designed fixed engines in part to facilitate ingress/egress via Valor cabin doors and to maintain fields of fire for crew-served weapons. Fixed nacelles also provide more volume for better component access and maintainability. According to the airframer and engine manufacturer, they simplify tiltrotor design and increase reliability by keeping components in a fixed-wing orientation.

The 7,000-shp AE 1107C on the V-22 is a twin-spool, axial-flow turboshaft with a 14-stage compressor followed by an effusion-cooled annular combustor, a two-stage gas generator turbine and two-stage power turbine. The Osprey engine also has dual full-authority digital engine controls. According to Wright, "The '-F' offers the same robust architecture, dramatically reducing development risks for the Army with fully validated models and operational performance data."

The modular Osprey engine is already an on-condition powerplant. According to Wright, "The AE 1107F on-condition maintenance approach coupled with the removal of disruption drivers on the AE 1107C reduces the maintenance burden to enable the customer to focus on the mission…" The AE 1107F also leverages engine health monitoring and other advances from other AE-series engines that improve maintainability, durability and reliability. Improvements on the AE 1107C have tripled time-on-wing over the last decade.

The 30,000-lb (13.6-t) FLRAA taxes its engines less than the 52,600 lb (23.9 mt) Osprey, and Wright noted, "The size and efficiency of the V-280 tiltrotor platform has allowed us to use this combat-proven engine at a reduced horsepower level, providing extended time-on-wing." The lighter Valor also allows the engine margin to grow as needed.

Defiant Demands

The Sikorsky-Boeing SB>1 demonstrated a very different approach to FLRAA mission requirements with its rigid coaxial rotors and integrated thruster. In March, the Defiant demonstrator with T55 engines flew 700 nm (1,300 km) from West Palm Beach, Florida, to Nashville, Tennessee, with two "hot" refueling stops. The big compound helicopter has dashed at 247 kt (460 km) in cruising flight, hauled a 3,400-lb (1,540-kg) sling load at 100 kt (185 km/h), and flown slalom maneuvers at 60–100 kt (110–185 km/h) on an ADS33 handling course.

Team Defiant selected the Honeywell HTS7500 for the Defiant-X FLRAA after evaluating several suppliers. "We are flying the HTS7500's parent engine, the T55, in the SB>1 Defiant as well as in our propulsion system test bed (PSTB). As the HTS7500 is based on the architecture of the T55, the engine that has reliably powered the Army's Chinook fleet for years, the HTS7500 will give Defiant X the power it needs to fly low, fast and far, land quickly and evade the enemy under the toughest possible operating conditions."

The venerable T55 is a twin-spool engine with a seven-stage axial and a one-stage centrifugal compressor, each powered by a two-stage turbine. The baseline T55-L-714A on today's Chinooks produces a maximum continuous power of 4,867 shp.

The new 7,500 shp-class HTS7500 draws on 60 years of T55 turboshaft experience enhanced with modern technologies to hike horsepower 42% and improve fuel consumption 18% versus the current production T55-GA-714A. According to Honeywell VP and General Manager for Military Engines John Russo, "By having the focus on Defiant-specific needs, we could optimize power-to-weight, optimize turbine temperatures for an application-specific design."

With benefit of 3D design tools, the HTS7500 would give a true FLRAA prototype sand-tolerant engines with reduced part count and turbine temperatures. Russo noted, "Because of the design

FVL at Sea

Future Vertical Lift described a joint-service program including notional replacements for Marine AH-1Z attack and UH-1Y utility helicopters and Navy MH-60R/S Seahawk and MQ-8 Fire Scout helicopters. US Marine Corps (USMC) Force Design 2030 shifted the Attack Utility Replacement Aircraft (AURA) to the Vertical Take Off and Landing Family of Systems (VTOL FoS). According to the Naval Air Systems Command, the Marines are not part of the Army cross-functional teams but still work with the Office of the Secretary of Defense, Joint Staff and the other services on the FVL FoS.

The Marine Corps is working on an FVL VTOL FoS capability-based assessment (CBA), which will be used to produce an initial capability document (ICD). The ICD is used to produce capability development documents for each of the capabilities desired in the FoS. These efforts will begin in fiscal 2023. Within the Marine Corps, key organizations supporting requirements documents are the Capabilities Development Directorate (CDD) Aviation Combat Element (ACE) Branch, the Deputy Commandant for Aviation (DCA)'s Cunningham Group, and the NAVAIR FVL program office.

AURA early concept design studies and service-level wargaming use mission effectiveness and aircraft concept design tools. Most of these toolsets are DoD standards and widely used across services. The Marines also employ a variety of model-based systems engineering (MBSE) and digital-engineering tools for requirements support and analysis.

The US Navy plans to develop and field more capable, maintainable and reliable crewed and uncrewed rotorcraft in the 2030 timeframe. The MH-60/MQ-8 Maritime Strike analysis of alternatives assesses the technical and operational feasibility, technical risk, and affordability of potential materiel and non-materiel solutions. The analysis of alternatives (AoA) will determine the most cost-effective alternatives to close service capability gaps.

The Navy is in the preliminary stages of an MH-60 service life assessment/extension program, reviewing aircraft usage data and critical fatigue-sensitive areas to determine airframe areas that may require additional structure support to extend the usable life. Once those areas are identified, fatigue models will be updated, and further analysis is performed to determine modifications.

tools, we came up with a solution that doesn't require exotic materials and coatings. It's actually very conventional materials. It's just how we packaged it given the weight of our compressor. We are comfortable that we developed a solution that meets their needs with low turbine temperatures and low part count."

The new military engine benefits from Honeywell's HTF product line of business aviation engines, credited with 99.99% dispatch reliability. "A lot of the reliability-centered design comes from the HTF7000 program," said Russo. "The controls and accessories package, it was key to this engine's reliability. We're expecting very similar reliability and maintainability based on the knowledge we got from that. All the lessons learned from the T55 are based on what the warfighter needs, what the maintainer wants."

Russo explained, "The control system, the center of it, takes lessons from the HTF7000 and the F124, the military turbofan we developed for the Taiwanese jet trainer. It's a fully redundant, dual-channel FADEC [full authority digital engine control]. It's got sensors to do continuous power checks. It has a digital twin, so we're monitoring what the engine should be running at based on all the information around it. We can try and find issues before they become problems that are expensive to repair. It's all on-condition maintenance because we have confidence in the control system to tell us when things are going off-schedule."

The FLRAA engine also draws on sand ingestion testing and other work done for the Honeywell/Pratt & Whitney HPW3000 improved turbine engine. Russo offered, "We've been working on the compressor design for a while now, and it's been through rig testing and a full engine test — we attach it to an existing engine. A second test is underway; we're going to do some ice-ingestion/ice-tolerance testing at Eglin Air Force Base… We couple the compressor with not-the-full-up Defiant-specific engine but an existing back-end with a brand-new front-end just to get the compressor mapped out from a performance/durability standpoint." Russo added, "You don't try to do everything at one time. We've focused on the compressor and got that right. Now we're turning to the back-end as well."

Under a cooperative research and development agreement with the Army, Honeywell began tests last November of the T55-GA-714C with the HTS7500 compressor for the Chinook. The 6,000-shp engine promises 23% more power and 8% better fuel consumption than the -714A in the Block I CH-47F. "We're trying to give the Army a lot of options," concluded Russo.

About the Author
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