Scaling Up Success

The SB>1 Defiant Joint Multi-Role Technology Demonstrator challenges Sikorsky and Boeing to grow the integrated X2 technologies

By Frank Colucci

The SB>1 Defiant JMR Technology Demonstrator scales up Sikorsky X2 rigid coaxial rotor compound helicopter technologies to achieve speed, range and agility far better than conventional helicopters. (Sikorsky graphic)

Speed and range improvements sought by US Army Aviation drove Sikorsky, Boeing and their Defiant team to scale up technologies flown on the 6,000 lb (3 t) X2 and 11,400 lb (5.2 t) S-97 to the 30,000 lb (14 t) class SB>1 Joint Multi-Role Technology Demonstrator (JMR-TD). A Systems Integration Laboratory (SIL) for Defiant came on line in December and a Transmission System Test Bed will run in 2016. The JMR-TD due to fly in 2017 is based on a 2013 Mission Performance Specification (MPS) for a medium-size Future Vertical Lift (FVL) platform to replace Army Black Hawks and other joint-service helicopters. "What we know as MPS and the evolving requirements coming from Fort Rucker are a moving target right now," acknowledged Sikorsky JMR-TD program director Doug Shidler. Specifics of the SB>1 Defiant design and manufacturing, and test plans are also guarded, but Shidler added, "We have a lot of parts in flow right now, and things are moving along. It is quite exciting to move along with what's in the art-of-the-possible for FVL Medium."

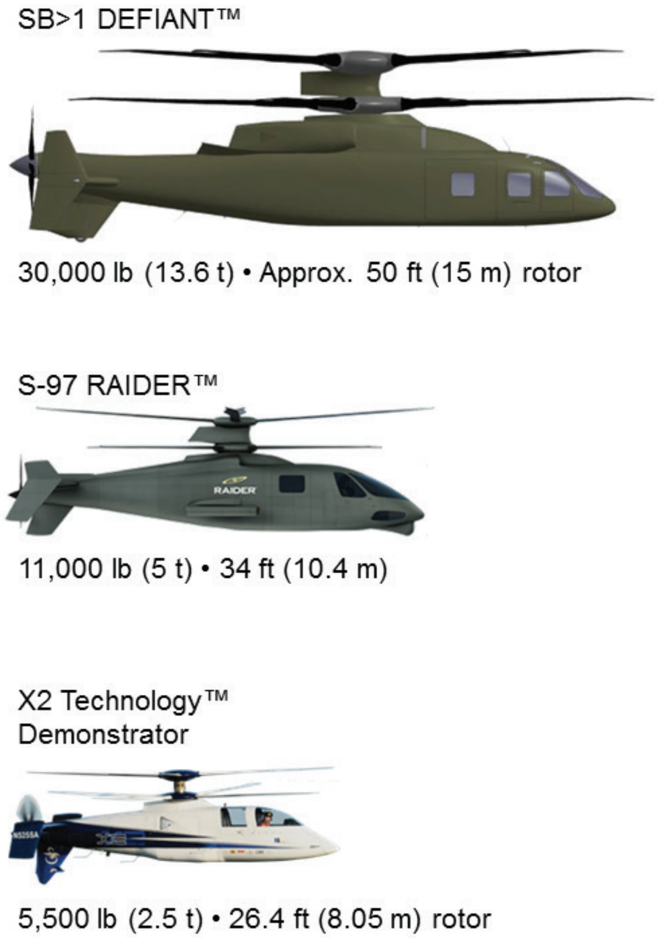
The MPS summary of FVL-M performance includes cruising speeds greater than 230 kt (426 km/h), vertical takeoff at 6,000 ft/95˚F (1,800 m/35˚C) density altitude and a combat radius of 229 nm (424 km) with four crew and 12 troops. The 250 kt (463 km/h) Defiant answers the specification with rigid coaxial rotors, an integrated tail propeller, optimized composite structures, fly-by-wire flight controls and active vibration control integrated in an FVL-M-size vehicle. High lift-to-drag main rotor blades and drag-reducing hub fairings address the speed challenges of a coaxial compound helicopter. The integrated technologies enabled the single-seat X2 demonstrator in level flight to exceed 250 kt (463 km/h) in September 2010 and began flight testing on the eight-seat S-97 Raider armed reconnaissance/special operations demonstrator in May 2015. Though the S-97 and SB>1 are separate programs with different requirements and different industry teams, Sikorsky Innovations vice president Chris Van Buiten previously stated, "Raider is risk-reduction for JMR."

Sikorsky and Boeing teamed up on the SB>1 Defiant in January 2013. Boeing program co-director Pat Donnelly said, "When we put this together, we were certainly very sensitive to the scaling issues of the X2 technology. Is it exactly an MPS-responsive vehicle? No — our engines are not next-generation engines. The cabin is MPS-compatible. The speeds are MPS-compatible. We're just going to fall short on range." The demonstrator will use two Honeywell T55-GA-714A engines like those now on the Boeing Chinook. FVL engine requirements are yet to be determined, but the Improved Turbine Engine Program (ITEP), now in competitive preliminary design, aims at a next-generation, 3,000 shp (2200 kW) class turboshaft with fuel consumption 25% better than today's Black Hawk engine. Donnelly concluded, "We've also done a lot of risk reduction so far, so everything is going well.”

An unpowered Defiant model underwent testing in the United Technologies Research Center wind tunnel in East Hartford, Connecticut, and the Defiant inlet design was tested in a Boeing wind tunnel in Seattle, Washington. Wind tunnel testing complements extensive computer modeling. Shidler summarized, “The results to date have been a Defiant design with all the performance that was predicted in our proposal, at a lower weight-empty fraction than previous X2 designs. That is, it scales as predicted.

“The prediction methodologies we used to size prior X2 designs are the same as those used for the S-97 Raider and are in the process of being confirmed by flight on Raider and shortly in the wind tunnel using a Defiant powered model in the NFAC.” Tests in the first half of 2016 at the National Full-Scale Aerodynamic Complex at Moffett Field, California will use a roughly 1/5-scale powered model of the SB>1.

Neither the Sikorsky Boeing rigid rotor coaxial compound helicopter nor the Bell Valor tiltrotor is an FVL-M prototype, but the 30,000 lb (14 t) class demonstrators will uniform government decision-makers on possible approaches to replace today’s 22,000 lb (10 t) Black Hawk in the air assault mission: “The Defiant requirements ask for a 50% higher payload to be carried twice as far in more stringent ambient conditions, at cruise speeds in excess of 230 knots [426 km/h],” said Donnelly. “These requirements require a design with better efficiency than the current fleet. The performance advantages over the current fleet extend to better maneuverability and agility, the ability to point the nose at a target in any flight condition, the ability to back away from adversaries, and in general, greater survivability throughout the mission. Defiant does this without the complication of reconfiguration to go fast, with better reliability and lower weight and cost than other concepts.”



The Defiant builds on the recent flight testing of the X2 Technology Demonstrator and the S-97 Raider light tactical helicopter demonstrator. Both development programs were self-funded by Sikorsky and its suppliers. (Based on Sikorsky graphics; corrected)

Coaxial Continuum

Weight fraction is an important parameter in the JMR Technology Demonstration. Sikorsky experience with high-speed coaxial helicopters stretches back to the 1970s with the Advancing Blade Concept (ABC) demonstrator (see “ABC Revisited,” *Vertiflite*, Fall 2009). The S-69/XH-59A with auxiliary jets attained 256 kt (474 km/h) and left Army pilots enthusiastic about the maneuverability, handling qualities, compactness and other advantages of the ABC in low-speed nap-of-the-earth and high-speed cruising flight. The ABC demonstrator was, nevertheless, heavy and fuel-hungry, and exhibited high vibration levels.

Sikorsky design teams considered conventional helicopter, compound helicopter, ABC and tiltrotor solutions to Light Helicopter Experimental (LHX) requirements in the early 1980s and briefed their LHX teammate Boeing on ABC technology in 1985. However, former XH-59A program manager and Comanche technical director Art Linden recalled, “While all this was going on, the Army determined that they had no need for speed greater than that achieved by conventional helicopters. Additionally, they set an arbitrary gross weight limit of 7,500 lb [3,400 kg]. Since the compound, the ABC and the tiltrotor all required additional mechanical components to achieve their higher speeds, it became fruitless to try to meet the gross weight limit and provide the ‘bonus’ of higher speeds along with all the other LHX requirements. The LHX was confined to the conventional helicopter configuration.”

Former Sikorsky advanced concepts engineer — and now Vertical Aviation Solutions president — Vaughan Askue noted, “Both ABC-type rotors and tiltrotors have worse weight fractions than conventional helicopters for different reasons.” With no hinges and extremely stiff blades, the original ABC rotor had an effective offset greater than 50%, imposing extremely high hub moments exacerbated by rotor loads applied in opposite directions. ABC blades, hubs and shafts consequently had to be heavier, and coaxial rotors added the weight of duplicate controls. High vibration, like that encountered by the XH-59, today requires engineers to add more weight in active vibration controls. A compound tail thruster drivetrain and controls like those on X2, Raider and Defiant introduces additional weight challenges.

“The tiltrotor presents a different set of problems,” said Askue. “In hover and at low speed, the entire weight of the aircraft, plus maneuver and safety factors, is carried at the wing tips.” Where lift loads for fixed-wing aircraft are distributed across the span with moderate bending loads, tiltrotor lift concentrates at the tips and requires heavy wing root structures. “In addition, you have to add the weight for the trunnions and machinery required to handle the huge loads from the proprotor while rotating the nacelles

The Sikorsky X2-coaxial Advancing Blade Concept (ABC) was originally proven on the S-69/XH-59, flown between 1973 and 1981. It demonstrated 263 kt (487 km/hr) in a shallow dive. (US Army photo)

and all the other stuff that has to reach the engine and transmissions such as fuel, hydraulics, electrical, controls, etc. through [angles of] 95 degrees."

The 280 kt (519 km/h) V-280 Valor couples tilting rotors to fixed engines to avoid some of the challenges and promises to fly smoothly and efficiently on fixed-wing lift. It still contends with the weight and downwash penalties of a stalled wing in hover or low-speed maneuvers. The rigid coaxial X2 compound helicopter overcomes retreating blade stall and advancing tip Mach barriers with two advancing blades for symmetrical lift and reduced rotor speed. Without a tail rotor, it maximizes hover and low-speed performance. "In addition, if you can squeeze the two rotors close together, the lower rotor can scavenge some energy from the wake of the upper rotor making the whole system more efficient," explained Askue. Depending on the mission segment, tiltrotors and rigid rotor compound helicopters both have their advantages. "Both can go fast, but there are serious tradeoffs in complexity, cost and risk."

The little X2 demonstrated modern-technology answers to ABC problems. The suite of X2 technologies subsequently migrated to the bigger Raider and still-bigger Defiant. The 230 kt (426 km/h) Raider with its single YT706 engine was designed for armed reconnaissance with two crew and up to six seated troops. It aims for an empty weight fraction around 68%. The bigger Defiant models a Black Hawk replacement. Figures for the SB>1 are undisclosed, but the notional Black Hawk replacement will cruise faster with a bigger load. Doug Shidler summarized, "When you compare Defiant and Black Hawk, the requirements issued from the BAA [Broad Area Announcement] are significantly different. The payload is 50% higher in more stringent conditions than a Black Hawk… The requirement was 230 kt or greater. We're at 250 kt. We're doing that while still retaining all the low-speed handling qualities of a conventional helicopter. The thruster provides a lot of maneuverability, particularly at the LZ [Landing Zone]. There's no reconfiguring of the platform to go high-speed or low-speed. You engage the propeller to go fast or slow down."

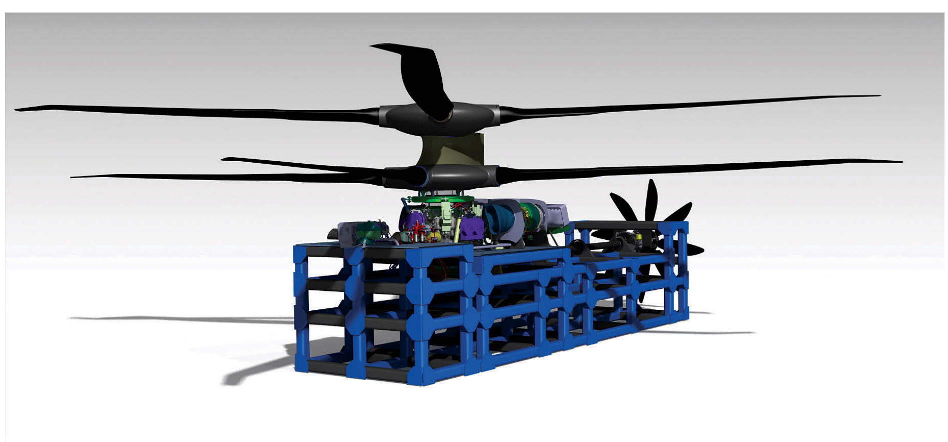
Sikorsky Defiant chief engineer Steve Weiner observed, "The basic features of X2 technology continue to be the same — fly-by-wire, active vibration control, integrated propeller, high lift-to-drag rotor, increased operational envelope, low pilot workload. All those features have been incorporated into Defiant, just like previous X2 designs. To date, the Defiant has all the performance with a lower weight empty fraction than previous X2 designs."

Weiner expected the Defiant weight fraction would approach that of the Black Hawk and added, "We're coming in where we expected to be when we first proposed these demonstrator aircraft." The SB>1 benefits from composite lessons learned in the CH-53K and other structures programs. "The Defiant airframe combines a primarily composite structure with metallic components in an engineered structure that minimizes weight. This general construction is similar to the Raider, but the different requirements for Defiant result in a different structure. There are also payload differences."

Defiant leverages work done on the X2 and Raider rotor systems. "Overall rotor performance, from both figure-of-merit and lift-to-drag ratio is as good or better than Raider," summarized Shidler. "The Defiant blades are similar to those on Raider as far as general planform and airfoil choice. However, the Defiant rotor diameter is larger due to greater payload requirements, and some of the performance goals of Defiant are different than Raider, requiring other minor differences. Defiant also includes manual blade fold, which is not a feature of the current Raider design. The incorporation of the fold feature, in combination with a different hub to blade interface has resulted in a different airfoil distribution than Raider."

Defiant blades approximate those of the UH-60M in size and those of the Raider in design. Weiner summarized, "As the basic requirements change, things like chord and diameter will change. They're certainly not identical, but they're not very far off either."

The XH-59A exercised differential pitch on its coaxial rotors to make snap turns, and coaxial rotors lowered disk loading to reduce turn radius dynamically. The X2, Raider and Defiant all share an auxiliary tail thruster integrated with the main rotors via fly-by-wire flight controls to provide forward and reverse thrust as needed.



The Transmission System Test Bed will run in 2016 at West Palm Beach. (Sikorsky graphic)

The 30,000 lb (14 t) Defiant demonstrator is designed to satisfy key parameters in the JMR Mission Performance Specification aimed at a Future Vertical Lift — Medium. (Boeing graphic)

Steve Weiner observes, "At this point, everything we've said in terms of G and maneuvering envelope still stands. With reversible thrust, we've got another thrust vector for backing away. The rigid rotor provides higher G at all speeds, and the most efficient 'bucket speed' is wider than [that of] a conventional helicopter as well."

Sikorsky Boeing has yet to disclose details of the Raider or Defiant cockpit controls. The SB>1 team has Systems Integration Laboratories in Stratford, Connecticut, and Mesa, Arizona. Fly-by-wire flight controls promise to make the pieces of X2 technology work together and optimize handling with reduced pilot workload. The Defiant, for example, has active rudders on the ends of its horizontal stabilizer. "They help with maneuverability, agility, and also with load management," explained Weiner. "And they keep the weight of the airplane down as well."

Building It Up

The Defiant JMR Technology Demonstrator will be assembled and tested at the Sikorsky Development Flight Center near West Palm Beach, Florida. The Sikorsky Boeing team includes more than 60 partners and suppliers supporting Defiant development. "Partners also invest in the product," explained Pat Donnelly. "Companies like LORD, Swift Engineering, we have them on the team doing what they do best." The Defiant will have a LORD active vibration control system, Parker actuators and a crashworthy Robertson fuel system.

Swift Engineering in San Clemente, California, is fabricating the major part of the SB>1 airframe. The company specializes in composite hand layup fabrication cured with or without autoclaves. Details of the Defiant work are still under wraps, but the company has a long history of high performance racecars, and in 2008 built the composite fuselage for the Eclipse Concept jet. Swift president and CEO Rick Heise, explained, "We have a heritage of rapid production vehicles from our racecar days. It puts us in a unique position developing prototype vehicles that are production representative… perfect for a demonstrator like the JMR."

Sikorsky and Boeing have yet to disclose their JMR work-split. "I think it's fair to say every IPT [Integrated Product Team] has members of both companies in it," offered Sikorsky chief engineer Steve Weiner. The contributions are further complicated by corporate acquisitions. Sikorsky is now a Lockheed Martin Company representing the largest line of business within the Lockheed Martin Mission Systems and Training (MST) business area. Lockheed Martin's MST and its Missiles and Fire Control (MFC) units are simultaneously the biggest Lockheed Martin participants in the Bell V-280 Valor. In mid-December, a Lockheed Martin link on the Valor web page led back to a Sikorsky page with a picture of a Black Hawk. Lockheed Martin spokesman Christopher Williams clarified, "The closure of the Sikorsky acquisition does not affect Lockheed Martin's or Sikorsky's partnering agreements on the JMR/FVL pursuit. Sikorsky is partnered with Boeing and we will honor that agreement. Lockheed Martin is teamed with Bell for the Mission System and we will honor that relationship. There are appropriate protections in place to protect Boeing's and Bell's data. There are no conflicts of interest and there will be no disruptions to the ongoing work."

IPLC Call For Papers

The joint AHS-AIAA-RAeS-SAE **International Powered Lift Conference (IPLC)** will be held in conjunction with the SAE 2016 Aerospace Systems and Technology Conference on **Sept. 27-29, 2016**, in Hartford, Connecticut, USA.

"Powered lift" encompasses all vertical and/or short take-off & landing (V/STOL) aircraft. IPLC 2016 focuses on advanced rotorcraft, jet lift concepts and technologies, and recent progress in electric propulsion applications to V/STOL.

The deadline for submitting paper offers is Feb. 26, 2016! The full Call for Papers and relevant information can be found on the SAE website at

www.sae.org/events/astc.

3rd Annual Transformative Vertical Flight Workshop

In conjunction with IPLC and ASTC, the 3rd joint "Transformative Vertical Flight Concepts Workshop on Enabling New Flight Concepts through Novel Propulsion and Energy Architectures" will take place from 1 p.m. on Sept. 29 to 5 p.m. on Sept. 30.

The objective of the initiative is to engage industry, academia and government agencies in developing a preliminary road map that will aid in the advocacy and pursuit of emerging technologies and approaches — such as electric/hybrid power and distributed propulsion — that offer the potential to fundamentally transform Vertiport-capable flight configuration designs and operational concepts.

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