Phase I Submission

Name of Program: Phantom Eye

Name of Program Leader: Brad Shaw
Phone Number: 314-777-7538
Email: bradley.j.shaw@boeing.com
Postage Address: The Boeing Company; P.O. Box 516, Building 598.2A, St. Louis, MO 63166-0516

Name of Customer Representative: Lt. Col. Ray Nelson, USAF, Missile Defense Agency
Phone Number: 505-853-3990
Email: raymond.nelson@mda.mil

Bio for program leader:

Brad Shaw has nearly four decades of experience developing manned and unmanned fixed-wing air vehicle systems for Boeing. In 2013, he was promoted from chief engineer to program manager for Phantom Eye, Boeing’s self-funded, liquid hydrogen-fueled, high-altitude long-endurance unmanned aircraft system. In this role, Brad is responsible for managing a team of nearly 150 geographically separated personnel, plus cost, technical, safety and schedule matters for this demonstrator program. Brad has managed every aspect of Phantom Eye’s engineering and vehicle management systems, ground control station, flight technologies, and test and evaluation for the air vehicle, avionics, and associated fuel and ground systems. Phantom Eye is currently preparing for its seventh test flight at the NASA’s Neil Armstrong Flight Research Center at Edwards AFB.

Prior to this role, Brad was the Integrated Product Team leader for Vehicle Management Systems on all variants of the Boeing X-45 Unmanned Combat Air System. He has held program and engineering leadership positions for a variety of Boeing’s advanced tactical aircraft platforms, as well as multiple customer and internally funded research and development programs.

Brad graduated with a Bachelor of Science degree in Electrical Engineering in May 1979 and earned his Master’s Degree in Engineering Management in May 1992, both from Washington University in St. Louis, Mo.

Brad manages all Boeing activities necessary to execute the Phantom Eye program and provide deliverables as scheduled per Boeing program management best practices. The team reviews technical progress against the planned activity as well as cost and schedule performance each week and holds monthly division reviews. Brad manages communications with the customer and the company via status reports and monthly program management reviews. Brad and the team lead Boeing and NASA flight readiness reviews before each test flight.

Brad’s ability to provide the team with clear direction, effectively delegate tasks, encourage team and individual accountability, and his excellent communication skills with team members and stakeholders are key facets of Brad’s outstanding leadership. Additionally, his excellent attention to detail ensures a safe and productive working environment for the flight test team.

As a leader, Brad maintains confidence and stays positive throughout the expected ups and downs that are all part of flight testing.
Background:
The Phantom Eye demonstrator, a Boeing-funded development effort, is a liquid hydrogen-fueled, high-altitude long-endurance (HALE) unmanned aircraft system (UAS) that economically provides persistent intelligence, surveillance and reconnaissance (ISR), Earth-sensing technologies, communications, missile defense, and other capabilities. The demonstrator is a lightweight, propeller-driven aircraft with a 150-foot wingspan, designed to reach an altitude greater than 60,000 feet, with up to four days of endurance while carrying a 450-pound payload.

Phantom Eye has proven the exceptional fuel economy of the liquid hydrogen propulsion system during six test flights between June 2012 and December 2013. Based on Phantom Eye’s successful demonstration of these technologies, Boeing is exploring larger HALE concepts that could stay aloft for a week or longer and carry payloads of more than 2,000 pounds. When properly equipped, a full-sized Phantom Eye can relay information across its 270-nautical-mile line-of-sight horizon.

The demonstration vehicle completed its first medium-speed taxi test March 10, 2012, at Edwards Air Force Base (EAFB), Calif., in coordination with the NASA Dryden Flight Research Center (DRFC). Phantom Eye, traveling atop its launching cart system, reached speeds of up to 30 knots as the ground team relayed directions and information using Boeing’s advanced Common Open-Mission Management Command and Control (COMC2) software.

Phantom Eye completed its first autonomous flight June 1, 2012, at NASA’s DFRC. The aircraft climbed to an altitude of 4,080 feet at a cruising speed of 62 knots. The flight was controlled using Boeing’s COMC2 software. Phantom Eye extended its endurance to more than five and a half hours during its sixth test flight Dec. 13, 2013, at NASA Dryden. Phantom Eye’s highest test altitude to date is 28,000 feet, achieved during its fifth test flight Sept. 14, 2013.

On June 5, 2013, the Missile Defense Agency (MDA) announced a $6.8 million contract modification, making it the first payload customer for Boeing’s innovative HALE unmanned aircraft. Boeing incorporated MDA’s flight instrumentation payload beginning with its fifth test flight.

On Feb. 5, 2014, Phantom Eye received experimental status from the U.S. Air Force 412th Operations Group, expanding the program’s testing opportunities. For Phantom Eye’s seventh test flight, scheduled for May 2014, the intention is to reach the program’s goal of achieving an altitude greater than 60,000 feet.

Program Excellence: Boeing’s Phantom Works business relies on three core principles: Engage to Understand, Innovate to Compete, and Prototype to Win. These tenets were the foundation on which Phantom Eye was built. By listening to customer needs, Boeing understood there was a growing capability gap for ultra-persistent ISR, compounded by today’s austere budget environment. Boeing engineers designed an innovative propulsion system for Phantom Eye with two modified Ford 2.3L four-cylinder engines equipped with three-stage turbochargers for high-altitude operation. The engines drive two constant-speed propellers that provide three times the fuel economy of conventional aviation fuel and produce water as the only byproduct. Boeing engineers redesigned, built, and successfully tested new propeller blades, keeping Phantom Eye testing on schedule for flight testing. It achieved experimental aircraft status by the U.S. Air Force in early 2014 after six test flights, demonstrating that Boeing Phantom Works’
rapid prototyping efforts can bring new and useful technologies to market quickly.

Nearly 150 subject-matter experts from almost every technical discipline across the company formed a nimble “Best of Boeing” team to bring Phantom Eye to the skies. Boeing employees from such organizations as Advanced Boeing Military Aircraft; Advanced Network and Space Systems; Global Services & Support; Boeing Research & Technology; and Boeing Test & Evaluation worked across the nation, from Philadelphia, Pa.; St. Louis and St. Charles, Mo.; Huntington Beach and Palmdale, Calif.; to the Seattle area. The biggest challenge facing Phantom Eye’s program leadership was satisfying the core program requirements with a team that was geographically scattered across the Boeing enterprise. Brad Shaw and his leadership team reinforced the importance of open, transparent, and timely communications as key to the program successfully and safely reaching its milestones. Phantom Eye team members responded to the challenge by quickly, effectively and efficiently sharing detailed information that was always time-critical.

**Teachable Lessons in Program Execution**

**Solidarity despite compartmentalized testing teams:** Rapid prototyping often requires iterative and segmented testing, which is especially challenging when aircraft systems are being lab qualified simultaneously with airframe manufacturing, then immediately turned over to test teams for aircraft integration. Phantom Eye was built in St. Louis with the understanding that it would have to be disassembled, transported, and reassembled at EAFB prior to flight testing. Program leadership prepared early for the many technical challenges of Air Vehicle Integration and Checkout (AVIC), and planned a unique hybrid approach to testing.

Before actual on-aircraft tests were performed, the Phantom Eye test team conducted stand-alone events to ensure proper design, function, and installation as precursors to more detailed integrated tests. With this approach, however, testing required constant coordination between the test team members and technical experts who provided design and analysis support. With clear communication and proper coordination by, this proactive and iterative approach allowed the test team to help identify and remedy numerous issues prior to shipping the aircraft to the test site.

Phantom Eye completed its initial AVIC in St. Louis in March of 2011, followed by the disassembly and shipping of the air vehicle from St. Louis to NASA DFRC. Ground testing of the liquid hydrogen-fueled flight propulsion system was conducted on a test stand at National Technical Systems in Santa Clarita, Calif., to confirm the engine nacelle and propellers were properly assembled prior to delivery to DFRC. Following aircraft integration of the propulsion systems at DFRC in May 2011, final AVIC testing was completed and the air vehicle was prepared for Structural Mode Interaction and Ground Vibration Tests (SMI/GVT).

SMI/GVT was a demanding event requiring expertise and equipment from an integrated test team of Boeing and NASA DFRC experts who worked tirelessly to coordinate navigation, flight control, vehicle management, loads, dynamics, and fuel systems support. The critical success of SMI/GVT testing was the result of extensive coordination and production of customized test documents, safety planning and the integration of schedules for 24-hour operations to perform the tests. Perfect synchronization of all these activities was required to ensure an effective and
efficient test. Phantom Eye’s technical team trained to perform test data analyses on site. This training, coupled with advanced dynamics test techniques developed by NASA DFRC, enabled Phantom Eye’s engineers to recommend on-the-spot refocusing of priorities, improving overall test efficiency. SMI/GVT was performed on time with no issues.

**Re-defining safety measures for a liquid hydrogen propulsion system:** With the hazards of liquid hydrogen, Phantom Eye’s fuel system required a focus on safety and detailed flight preparation procedures more like a spacecraft than an airplane. It was critical that all team members understood that a slower and deliberate fueling process could not be compromised by the stresses of typical high-tempo test environments. During testing, the team developed a specialized concept of operations for safely fueling, moving, operating and defueling the air vehicle with hazardous liquid hydrogen, which also included using a simulated cryogenic fuel.

The team performed numerous fully integrated fueling, defueling, and engine run tests on the NASA DFRC ramp as part of this dedicated training plan. These tests required the development of custom liquid hydrogen fueling and defueling procedures, as well as unique methods to restrain the vehicle during full power testing without damaging the lightweight airframe structure. Essential coordination was completed with the distributed team and DFRC to ensure that electrical power, tie-downs, communications, specialized firefighting teams, and other support equipment were available for testing at the designated location with 24-hour support for multi-day operations.

**Masterful coordination for testing a non-standard aircraft:** The integrated test team needed to become familiar with additional innovative systems on Phantom Eye once it graduated to Combined Systems Testing (CST) in February 2012. For example, the air vehicle taxis and takes off from a wheeled launch cart, requiring new detailed instructions and additional ground safety measures. Its rear landing gear uses a skid instead of wheels, allowing the air vehicle to come to a stop, then rests on a wingtip after landing. Afterward, it is hoisted back onto its cart and towed to the hangar. With all testing on a dry lakebed runway, weather constraints were constantly monitored and evaluated to ensure the safety of the ground crew and the aircraft.

The biggest leadership challenge during CST was to build on all previous testing to safely demonstrate the operation of the complete Phantom Eye system. This testing was the first time all of the systems were tested simultaneously on the vehicle, bringing Phantom Eye to life and preparing it for taxi testing. While many of the subsystems and components had been tested independently, the integration of the entire system revealed new issues and led to several iterations of the established test-fix-test cycle. Each technical challenge was overcome by the open communication and collaborative working environment established by program leadership early. Phantom Eye’s success during CST demonstrated its communication links, engine settings, pilot-initiated command and control, emergency procedures and autonomous functions.

After CST, taxi testing validated the aircraft’s performance, stability, and directional control up to 40 knots on the ground. These ground tests were another complicated challenge because the vehicle’s launch cart system is radically different from air vehicles with traditional landing gear. The lessons learned on these tests led to the development of integrated propulsion and
aerodynamic control laws for taxi control, and an improved understanding of how the vehicle handles on the cart. This testing also served as a graduation exercise for the multiple control rooms, communications links, the launch team, pilots, and telemetry consoles. Taxi testing also required realistic lakebed recovery rehearsals, which improved the vehicle recovery processes and minimized the time required to safely return to the fueling area.

“One Boeing” team returns Phantom Eye to flight in record time: After completing all ground and taxi testing, the Phantom Eye demonstrator graduated to flight testing. This required the sterilization of local airspace, a chase aircraft, weather balloon support, continuous monitoring for very specific weather conditions, as well as fully functioning components of the Phantom Eye system. A detailed, integrated timeline and schedule ensured that the first flight would fit into the narrow operations window provided so as not interfere with other EAFB operations. Three days of preparatory activity had to be executed flawlessly to be ready for the two-hour window allotted between sunrise and the resumption of normal flight operations for the base. Phantom Eye’s historic first flight occurred on June 1, 2012, with the aircraft climbing to an altitude of 4,080 feet and reaching a cruising speed of 62 knots. The flight was performed as planned and was indistinguishable in execution from training simulations.

During the landing rollout, however, the aircraft experienced an anomaly with its landing gear on the dry lakebed, resulting in its collapse. The team immediately executed time-sensitive emergency landing procedures on the vehicle, which was still full of liquid hydrogen. A testament to the program’s leadership, everyone’s training, teamwork and dedication resulted in the safe and efficient recovery of the vehicle, with only minor damage to the landing gear.

The Phantom Eye team worked across Boeing during the next several months to develop a more robust landing gear system, using the expertise of engineers who work on F/A-18 and F-15 landing gear systems. Using this “One Boeing” approach, these landing gear experts immediately completed a Root Cause Corrective Action process, a Lean+ tool that begins with clearly defining a problem and analyzing and understanding its causes before making any changes. Within a few weeks, the team collected data necessary to begin to design a stronger landing gear, similar to that used by a fighter aircraft. What would normally take more than a year, this agile “One Boeing” team of engineers redesigned, tested, manufactured, and reinstalled Phantom Eye’s new landing gear within a few short months. Their hard work paid off, as Phantom Eye returned to flight Feb. 25, 2013, climbing above 8,000 feet and remaining aloft for 66 minutes before making a perfectly benign landing.

Summary: Over the past three years, the Phantom Eye program has achieved incredible success due largely to leaders like Brad Shaw who optimized testing plans, and worked out many new challenges for such an innovative propulsion system. Outstanding coordination of a team in various locations across the United States, expert leadership, a common “One Boeing” philosophy, and steadfast dedication to rapid prototyping have made affordable and persistent intelligence, surveillance and reconnaissance a reality.