Unmanned Multirotor Aircraft System

Fast, deployable craft for the enhancement of the small unit's situational awareness

by Ed Darack

Unmanned aircraft systems (UASs) play continuously expanding and ever more salient roles in an increasing range of military (and civilian) applications and operations. Technology driven, with designs and capabilities evolved and enhanced through user feedback, these platforms expand the breadth, depth, and speed of C^4ISR/C^4ISTAR (command, control, communications, computers, and intelligence, surveillance, and reconnaissance/command, control, communications, computers, intelligence, surveillance, targeting, acquisition, and reconnaissance) capability primarily through imagery intelligence platforms. Other utilities include weapons delivery (MQ–9 Reaper) and logistics (K-MAX), with a broad range of other functions emerging, to include electronic warfare, assault support, and network communications relay.

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A ground static operation made demonstration as proof of concept. *(Photo by author.)*

Practitioners have very successfully developed these systems for and have implemented them at the strategic and operational levels, and to a lesser extent directly for those at the tactical level. Despite their growth and technological advancement over the past decades, however, much remains for system development specific to the needs of the platoon, squad, and fire team, warfighters who realize the greatest benefits of what currently available technology can provide.

Concept

How may system designers exploit currently available UAS and related technology to most significantly bolster the ground warfighter's potency and survivability, in all types of terrain, day and night, in all types of conditions? Conceptually stated: dramatically enhance situational awareness within his "immediate battlespace"—that which lies directly before the warfighter at any given instant in time. The grunt's real world—day-in, day-out, for months at a time—is the immediate battlespace, which describes the ultimate tactical realm, unknowable by anyone other than the grunt and his unit compatriots at that place and at that time, regardless of higher echelon C^4ISR efficacy.

In an urban environment, the spatial extent of the immediate battlespace may span a radius of just 50 feet (or less); in an open desert environment, the immediate battlespace may stretch over 1 mile in any given direction. But temporally, the immediate battlespace always, in all types of terrain, exists only at one instant in time—right now, at this very moment. There are no "time windows" in the immediate battlespace during which intelligence products may be passed to the warfighter by a non-

Launching an RQ–11B Raven UAS at a FOB in Helmand Province. *(Photo by author.)*

collocated UAS operator. Imagery or intelligence derivations of an imagery product (such as a radio-transmitted description of an enemy combatant's movements based on UAS feed) can become obsolete within 1 second, negating the utility of currently fielded UASs commanded by operators not collocated with the warfighters themselves. LtCol Kain Anderson notes that the emerging ability to pass sensor control of a large UAS to warfighters at the microtactical level still requires detailed coordination of an expensive, high-demand, low-density platform. Detailed coordination takes time, and time is the one commodity that warfighters at the microtactical level do not have when engaged in an operation/firefight.

At any given instant, a warfighter's direct visual situational awareness is limited to the two-dimensional plane along which his eyes scan, either directly, through an advanced combat optical gunsight (ACOG), or through other optics. Furthermore, he cannot see through walls, over a hill, around a stand of trees, into a darkened hallway, or around a street corner, all of which may conceal lethal hazards. A small airborne craft, launched and commanded by the warfighter onsite, can provide real-time imagery of exactly what he needs, "three-dimensionalizing" his and his fellow warfighters' situational awareness of the immediate battlespace by providing a remote omnidirectional visualization capability, dramatically boosting his and his fellow warfighters' operational potency and survivability.

Instead of UAS capability standing conceptually to the rear of the warfighter, providing "top-down" information flow temporally irrelevant to the immediate battlespace as is the case with most instances of currently fielded systems, a platform for the small unit in the immediate battlespace should work directly with him, at his direct command, fluidly integrated into his unit's scheme of maneuver, regardless of dynamism of the moment, without interfering with or diverting his attention from his primary, secondary, and even tertiary duties.

Creation Process and Description of Capabilities Required

System designers should first carefully analyze specific needs of the front line, small unit, ground warfighter and then exploit existing technology to create a custom-hewn platform for him, rather than trying to wrap his needs around currently fielded systems. This happened for me by accident. I never embedded with Marines to create a UAS, but while with small units, I clearly saw the utility of such a system emerge dramatically before my eyes.

The system should be first and foremost "infantry-centric" in that the system is man-portable, very lightweight, small, fast-deployable on a need-triggered basis in any terrain, even the "tightest" terrain, such as inside a forest or in urban environments. Launch, flight, and recovery should require no user exposure to potential enemy threat. The system should operate quietly with inherent stealth and minimize "attention sacrifice" from the warfighter's primary, secondary, and even tertiary tasks during all aspects of operation, mitigating the warfighter's potential for task saturation while greatly enhancing his and his unit's situational awareness (no "gadget-sclerosis" that clogs and bogs down an operation). The platform should be designed and constructed to be extremely survivable, strong, and able to operate in a full spectrum of conditions in all types of environments, from polar to desert, from mountain to jungle. Mission critical components should be redundant to ensure task completion even in the event of a failure, and all components should be quickly replaceable in austere field conditions.

The system should provide stabilized, static, real-time imagery even in adverse gusty and erratic wind conditions, day and night, with the ability to visually inspect a subject in detail, and further have the ability to land under user control, power down, and maintain a continuous feed of real-time imagery of a subject (ground static observation mode), then move under user command to another location if necessary, and do the same. The system should provide imagery with relevant symbology and data overlay, similar to what heads-up displays provide pilots of manned aircraft, as well as having an onboard, tamper-proof, encrypted, high-definition solid-state recording means for after-action detailed processing (of raw, high-definition imagery, without any overlay, but with time-coded metadata recorded separately), usable for a variety of purposes. The platform should be able to provide imagery not only to the system commander, but also to others in his unit, with a "command handover" function so that others may control either the aircraft platform, the visualization sensor package, or both. The system should include means for enhancing situational awareness of the immediate battlespace for others inbound toward the location of warfighters at that immediate battlespace, including other ground-based troops, higher echelon UAS, and manned aircraft, providing "bottom-up" flow of information for the overall C^{4}ISR "build" for these inbound entities.

The system should include a variety of command modes, from direct user commanded to semiautonomous, to hybrid, with joystick, touchscreen, and voice command user interface capability. Operation of the system should be self-coordinating and -integrating with other platforms, manned and unmanned. It should be inexpensive, with some bands of its mission spectrum being sacrificial, including "infrared beacon marking" to enhance situational awareness for inbound close air support assets as well as true onsite battle damage assessment through onboard, tamper-proof, encrypted, solid-state recording of high-resolution imagery, to be recovered after the fact. The system should be designed to be simple at all levels, including utilizing a single power source. The system should be designed from the outset for expandability for a range of future infantry-centric situational awareness enhancement utilities such as multispectral scanners and other active/passive arrays, and also to be able to be integrated into the greater C^{4}ISR package, including integration into in-place systems such as Blue Force Tracker. LtCol Anderson noted the need to make a reference to the USMC Combat Development & Integration UAS family of systems concept paper currently in editing, due for release in 2015.

Nothing currently fielded by the Marine Corps comes even remotely close to providing such capabilities, with primary VMU squadrons flying Group 3 (Group 3 aircraft weigh less than 1,320 pounds, operate below 18,000 feet above mean sea level, and fly at speeds less than 250 knots (indicated airspeed)) and larger fixed-wing UASs, which cannot provide true static imagery, cannot remotely land and relaunch for "ground static observation mode" (alternatively called "perch and stare"), and cannot launch and land in tightly confined environments like forests and dense urban terrain, among many other relative shortfalls. However, technology exists that would allow such a system to be fielded within 12 to 18 months based on multirotor technology. (See Figure 1.)

The Multirotor

Typically composed of centrally interconnected, symmetrically configured radial arms, each arm rigidly supporting a single or set of two coaxially configured motor-rotor assemblies at arm's extremity, multirotors have proliferated in recent years due to advances in electronic processor speed and miniaturization of flight diagnostic componentry. A multirotor uses the thrust and torque of three or more rotors to ascend, descend, pitch, roll, and yaw the craft, providing a full "6 degrees of freedom" through the air. With multiaxes solid-state microelectromechanical system inertial measurement units (MEMS IMUs), including accelerometers and gyroscope feeding thousands of packets of flight attitude and other performance data per second into a flight controller composed of a core of parallel processing com-

Unmanned Aircraft Systems Catagorization Chart

UAS Group	Maximum Gross Takeoff Weight (lbs)	Normal Operating Altitude (ft)	Speed (KIAS)	Representative UAS
1	0-20	< 1,200 AGL	100	Wasp Raven Puma
2	21-55	< 3,500 AGL	< 250	Scan Eagle Silver Fox Aerosonde
3	< 1,320	< 18,000 MSL	< 250	STUAS Shadow
4	> 1,320		Any	Fire Scout Gray Eagle Predator
5	> 1,320	> 18,000 MSL	Any	Reaper Global Hawk BAMS

Figure 1. (DoD UAS Roadmap, Washington, DC, 2013.)

puters, a multirotor, even a very small craft (5 to 8 pounds and spanning less than 2 feet in the longest dimension) can navigate through the air extremely quickly and nimbly and come to a very stable hover in both still and extremely gusty and erratic winds, providing the capability for a truly static view of a subject. During my research, I determined that the "Y–6" configuration, with two coaxially mounted motor-rotor assemblies at the end of each of three equally spaced arms, to be the best of all types of multirotors for an infantry-centric aircraft visualization system. The Y–6, which could also be called a coaxial hexa-rotor, can be built very small yet powerful (with six total motor-rotor assemblies), provides a wide field of unobstructed view with just three arms (important for wide field visualization), move in any direction at speeds up to 50 miles per hour, and, with two motor-rotor assemblies at the end of each arm, has built-in redundancy if a motor fails. The Y–6 can also be designed to fold into a small yet easily and quickly deployable package. Furthermore, with miniaturization of electronics, I found that engineers could pack a number of individual systems onto the craft. With research completed, I designed a proof-of-concept craft and successfully built and test flew it.

Aircraft

Aircraft body. Such a craft is best constructed from modular machined carbon fiber plate and tube, individual modular parts being mechanically interconnected with black anodized hex cap screws and anodized aluminum locking "Nylock" bolts. Size of the aircraft, combined with low-altitude flight, black color, and low noise signature makes it "stealth" to any radar as well as to the eye. While this means of construction proves heavier than molded carbon fiber, it is extremely strong, allows for quick part replacement (with a field "crash pack"), and grants easy access to components. Carbon fiber is very strong and light, and has excellent vibration dampening characteristics, important for isolating vibration-sensitive MEMS IMUs on the flight control module. The craft I constructed crashed a number of times, once from over 30 feet in the air, yet sustained only a few scratches to the body and no damage to the internal components.

Aircraft power, motors, wiring and connectors, and rotors. The lithium polymer battery best supplies power, which is very light. The system I constructed could fly from 12 to 15 minutes per battery (currently available batteries could power a craft described here and all systems for upwards of 30 minutes of flight and upwards of 12 hours of static ground observation). Such craft perform best with brushless "outrunner" motors, weather-sealed for adverse conditions, using lightweight, high-efficiency electronic speed controllers for precision flight performance. Fine-strand, flexible wiring works best on such craft. Connecting individual components such as speed controllers and motors with gold-plated bullet connectors instead of direct soldering means that, combined with the modular construction of the body, the connections allow users to quickly field-replace parts, if necessary. Rotor assemblies are best constructed with a central titanium hub with three or four hinged carbon fiber rotor blades, each with reinforced leading edges and tips. Reinforcement combined with hinging, while increasing weight, dramatically increases survivability in the event of a blade strike, and also reduces the size of packed craft. A higher number of rotor blades per hub increases amount of thrust per revolution, reducing motor speed necessary, hence noise signature.

> ***Furthermore, with miniaturization of electronics, I found that engineers could pack a number of individual systems onto the craft.***

Flight control, guidance, and spatial proximity awareness systems. The core flight control computer takes input from solid-state MEMS IMU accelerometers, gyroscopes, an aneroid barometer, and user commands for primary flight control. Onboard GPS with high refresh rate antenna (10 cycles per second (10 Hz) or more) will provide precision guidance and location information to be used by the operator, as well as enable a number of user modes, including waypoint navigation, return-to-base, return-to-mobile operator, and "virtual tether," where the aircraft maintains a continuous distance from the operator as he moves. An omnidirectional spatial proximity awareness system, utilizing either LIDAR (light detection and ranging), ultrasonic sonar, or infrared will allow the system to avoid colliding with objects such as doorways and trees, and combined with GPS, allow an autolaunch and autoland feature, allowing the operator, even while low crawling, to deploy the system with less than 15 seconds of partial attention sacrifice. Collision avoidance also allows the platform to operate in virtual tether mode in confined terrain including urban and dense forest. Proximity awareness also allows the platform to be confidently deployed into situations where GPS is unavailable, such as into a darkened room, under direct user command.

The aircraft will have a set of receivers and transmitters for a variety of user command modes, from direct command to semiautonomous, to virtual tether, receiving information from the primary user and transmitting flight and positional information to his mobile command system.

Visualization System

The system should be based around a dual mode (visible wavelength/infrared) high-definition digital video camera with optional high-definition capability and simultaneous still capture for both day and night use. Optical zoom will enable a view from wide angle to telephoto. The camera should have onboard flash memory for recording raw high-definition video. The system should include a bank of high-intensity white and a bank of high-intensity infrared light-emitting diodes (LEDs) for illumination when required by the user, such as in a darkened room. Solid-state infrared laser, coaxially aligned with the camera, should be included to be used as a pointer to aid other ground units or manned and unmanned aviation platforms to build situational awareness. A bank of high-intensity infrared LEDs on top of the craft will aid in either marking a target, marking location of friendlies, or simply to aid in a "talk on" for aviation platforms. A camera with banks of LEDs and an infrared laser will perform best if mounted on a three-axis gimbal mount. A gimbal mount maintains a continuous level horizon and vibration-free view while flying and hovering, even in adverse gusty and erratic winds. The gimbal mount may be "locked forward" to the aircraft so the user may see exactly what lies before the front of the craft, "locked on direction" to show what lies ahead of the craft, regardless of direction of flight, or "free," where the user (either primary, or to one that the primary operator "handed off" control) can scan the camera in all directions and tilt the camera up and down as the aircraft hovers or flies. In a ground static observation mode, the free gimbal mount will allow a user to scan throughout an area from the aircraft's perch, zoom into a subject, and mark the subject with the infrared pointer, and even mark itself with its top infrared strobe bank. A flight controller will overlay relevant information, such as altitude, distance from user, heading, speed, battery voltage, camera mode, flight mode, and GPS coordinates, and transmit the real-time feed, with an overlay, back to the user via onboard video data transmitter.


Technology already exists to build these systems. *(Photo by author.)*

User Interface System and Maintenance System

Based around a lightweight, small (less than 6 inches), ruggedized high-contrast controller/display with touch-screen capability and deployable anti-glare hood, the primary controller will have two removable, wireless thumb controllers, one mounted on the right of the display and one on left. A lightweight command transmitter/receiver set for communications with aircraft can be stand-alone or helmet mounted, wirelessly connected to primary controller/display. Thumb controllers should include a thumb stick control and a series of switches and a dial for user control of the aircraft and onboard systems. A screen should be able to be mounted to a MIL-STD-1913 rail of an M16, M4, M249, or other system, via articulated arm, eye level with an ACOG or other sight, with one detachable thumb controller mounted on the rear grip of the weapon and the other on the fore grip of the weapon. This configuration allows a near-instant view "from above," providing situational awareness of what lies around an otherwise blind corner, over a hill, or in a dark room, all while maintaining a "weapons-up" stance. In this scenario, a user may proceed with his duties as a rifleman, seeing the world either directly in front of him with his naked eyes, through his ACOG or other sight, and then within a quarter of a second, gain instant three-dimensional situational awareness of the immediate battlespace by glancing to the screen next to the weapon's sight.

During the entire time the aircraft is activated, a user may command it to hover, proceed along a preplanned route via waypoints entered on the touch-screen with displayed geospatial data, such as digital maps, Google Earth, or Falcon View, maintain a virtual tether, or fly via direct user command either through weapon-mounted or handheld controls, or through a speech recognition system that processes basic commands such as "go to waypoint A" or "go to grid 42SXD3752904523," "hover in place," "camera to heading 270," "camera down 15 degrees," etc. The user will easily be able to scroll through command and visualization screens, either by voice command or by dial control, similar to a pilot's multifunction display. LtCol Anderson noted to reference Maj Justin Anderson's 2012 School of Advanced Warfighting thesis paper ("Tying Marines into a Common Operating Picture: Lightening the load and decreasing uncertainty") where he discusses a thin film (tape) that can transmit voice electronically—without a traditional microphone. This would be critical for voice commands as described because the noise level during a firefight may drastically degrade the performance of a traditional microphone, just as snipers may need to maintain such a low signature that they can only whisper. The user will also be able to easily change command modes during operation from direct command to virtual tether to waypoint to emergency return to base/user.

Other notable systems include low-battery warning, hover in place during moments of no control input, return to a specified location if no user commands come during flight for a specified period of time (in direct-command mode), power conservation mode during static ground observation mode, and autoreturn to the mobile commander at a specified low-battery threshold, among many other potential systems.

The maintenance system would include battery chargers, a universal tool to repair parts, spare rotors, rotor assemblies, all components, and soldering station.

Training

Approximately 1 to 2 weeks for full flight, maintenance, and repair training would be required. This training should include the very important process of self-coordination and integration with other UAS and manned aircraft, including setting "hard" stay-below altitudes.

An oblique view of a potential system. ***(Photo by author.)***

Future Expanded Roles

The complete system described above can be built with existing technology. With miniaturization of electronics, many other features may be placed on a small multirotor system in the future, such as synthetic aperture radar for on-site instant or near-instant "ground penetrating" scanning for improvised explosive devices and weapons caches and other future technology-enabled utilities. LtCol Anderson also notes the necessity of an encrypted transmission capability. Just like night vision goggles allow the warfighter to see in the night, conceptually this system allows him to see through walls and around corners.

>Author's Note: The idea for the proposed system described in this article emerged as I undertook a project to conceive, design, engineer, build, and fly a functional unmanned aircraft system and compose a feature article about the process for a national aviation magazine. I was first inspired to create such a platform in September 2005 while embedded as an independent writer/photographer with a platoon of Marines in eastern Afghanistan's restive Kunar Province. Subsequent to that first experience, I embedded with Marine Corps and other units a total of three more times in Afghanistan and twice in Iraq, as well as visiting combat training facilities in the United States dozens of times over the course of the following 6 years. I spent the majority of this time with small infantry units based in austere environments, but I also embedded with a spectrum of aviation squadrons, both combat deployed and in training, as well as embedding at MAGTF training facilities including a number of times at Marine Aviation Weapons and Tactics Squadron 1 and Tactical Training Exercise Control Group and also weeks-long embeds with units training at the Marine Corps Mountain Warfare Training Center. While the project for the aviation magazine, published in July 2014, proved a success, I felt I should describe the entire unmanned aircraft system (UAS, inclusive of the unmanned aerial vehicle itself) I had designed, as I developed it for a very specific, very relevant and important, yet unaddressed purpose. The scope of the project, however, proved greater in length and technical depth than appropriate for a general readership publication. I believe that the system described in this article (or one substantially similar), if successfully fully developed and implemented, will add tremendous capability to the infantry platoon, squad, and fire team, as well as scout/sniper teams and members of other Services' small units, including those of U.S. Special Operations Command.

LtCol Kain "Chewy" Anderson, CO, Marine Unmanned Aerial Vehicle Squadron 1, and other UAS subject matter experts provided technical review of this article. Review implies neither endorsement nor opposition to such a described system.