Can Group 3 UAS Be Relevant in a Major Conflict?

A case for greater automation, today

by Maj David D. Zyga

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The *National Defense Strategy* states that the U.S. military will invest broadly in military application of autonomy, artificial intelligence, and machine learning.[1] The Department of the Navy promotes a strategic imperative to exploit autonomous technologies.[2] The *Commandant's Planning Guidance* (CPG) encourages us to exploit revolutions in automation and artificial intelligence.[3] Even the *Marine Aviation Plan* is rife with examples of how autonomous systems will enhance and expand our warfighting capabilities.[4] Yet as I look around my small corner of the MAGTF, I am not seeing much evidence that autonomous systems are tactically employed in a meaningful fashion, and I'm a UAS Officer.

Our executive-level guidance to make greater use of autonomy and artificial intelligence can give the impression that autonomy, in and of itself, is the mission. This is not the case. The mission is to be a naval expeditionary force-in-readiness.[5] Autonomous systems are merely tools adapted to a new environment to achieve this end state. As I hope to demonstrate in this article, automation can be affordably applied to our current legacy systems to expand capabilities and mitigate some limitations.

The CPG describes an operating environment that requires long-range, low-signature systems.[6] Our current and near-term small UAS (SUAS) and small tactical UAS (STUAS) fail in both categories—they were designed for a more permissive local environment. Moreover, our "unmanned" systems often carry a higher personnel requirement than many "manned" counterparts, contrary to the goal of a lighter, more agile force. Compounding the challenge is our current UAS dependence on electromagnetic (EM) spectrum supremacy, which is critical to control the aircraft and consume the sensor products: this supremacy cannot be assured in modern conflict.

The examples in this article will center on the RQ-21A, our current STUAS Program of Record. However, these concepts equally apply to any category UAS. My intent is to demonstrate that we need not await a sophisticated future program to begin reaping the benefits of automation.

Autonomy and Automation Explained

Those familiar with UAS operations may recall five levels of interoperability (LOI), ranging from LOI 1 (indirect receipt of telemetry and sensor data) to LOI 5 (full aircraft control, including terminal area operations). Similarly, "autonomy" is not simply defined in binary terms—there exists a spectrum of control retained by the human and the machine.

"Autonomy" is glamorous; "automation" is not. "Autonomy" is an oft-misunderstood (and misused) word; it simply implies a certain level of independence from human intervention: my navigation software is autonomous because it automatically reroutes when it senses that I'm straying from the recommended path. "Automation" implies some level of human input, but removed from realtime: my coffee machine is automated because it starts brewing coffee at the time that I program it to.

There currently exists no single authoritative standard that clearly defines levels of autonomy, nor would such a taxonomy be useful for all applications. For the purposes of this article (and for the sake of brevity), I will paraphrase a standard proposed by the Massachusetts Institute of Technology.[7] (See Table 1 on next page.)

The reader will notice that "automation" does not explicitly appear in this sample taxonomy. For the purposes of this article, I submit that "automation" be considered to replace human commands—the human still gives the commands, but asynchronously (i.e. non-real time). Where decision authority exists, the human operator commands their pre-made decision based on percepts (conditions that the system senses) and incepts (conditions provided by a human).

These levels of autonomy (LOA) do not necessarily imply that a system is capable of only a single level; in fact, it is common for a system to function at different levels for various tasks, and even transition between autonomy states for the same task. My vehicle maintains

Autonomy Level	Description	Colloquial Analogy
1	Human gives commands, with no machine assistance	Teleoperation
2	Human gives commands, with several machine-aided options	Low-level decision support
3	Human gives commands, with few machine-aided options	Medium-level decision support
4	Human gives commands, with single machine-aided option	High-level decision support
5	Machine makes decisions, with human approval	Human-in-the-loop
6	Machine makes decisions, with human veto power	Human-on-the-loop
7	Machine makes decisions, and informs human	Human-near-the-loop
8	Machine makes decisions, and informs human upon request	Human-aware-of-the-loop
9	Machine makes decisions, and informs human if it decides to	Human-unaware-of-the-loop
10	Machine makes decisions, and does not inform human	Human-not-required

Table 1. Taxonomy of autonomy.

speed generally via LOA 1 (accelerator pedal) or LOA 6 (cruise control). An RQ-21A example would be the operator manually flying the air vehicle (AV) with heading and bank angle (LOA 2) or commanding it to a pre-programmed route with specific parameters (LOA 7).[8] Another example is manual sensor turret control (LOI 1) or commanding an auto-track (LOA 10).

As previously noted, human control need not occur synchronously: operator instruction may be input prior to the decision event, and the machine executes the commands based on internal and external stimuli. Likewise, the act of informing the human may also occur asynchronously, via post-mission reports. The human is removed in both time and space from an automated machine's actions.

Benefits and Drawbacks

Natural debates arise about the military gains and losses of automation. Here are some benefits and drawbacks of increased Group 3 automation as I see them.

Benefits:

- The greatest vulnerability of a UAS, in my opinion, is the datalink. Most Group 3 systems use a line-of-sight (LOS) link to support the constant command and control (C2) uplink and sensor/telemetry downlink. Beyond-line-of-sight (BLOS) links to support sensor streams can be costly and resource-intensive. Moreover, even with frequency agility, the quality of the datalink is still subject to electromagnetic interference (EMI) and targeting by adversarial electronic warfare and intelligence systems. To emit is to be targeted. This is why naval vessels routinely operate under emissions control (EMCON), potentially precluding the use of a ground control station (GCS) emitter. The AV itself is *relatively* low-observable compared to many legacy (manned) aircraft, barring the constant omnidirectional radio frequency (RF) emissions. Many counter-UAS systems exploit the datalink through detection and disruption. The datalink is the weakest link.
  - There exist emerging datalink technologies that address some vulnerabilities inherent to current systems. I assert that higher operational usage rates will inevitably lead to faster obsolescence via adversary detection and countermeasures, the demand for assured communication will likely exceed our capacity to supply it, and the recurring costs of usage are justified only a fraction of the time they are being actively utilized. Assured communications should be reserved for those situations that truly require it; I argue that a non-trivial percentage of UAS operations fall outside this category.
- In many cases, the LOS datalink also defines the maximum range, and hence operating radius, of the AV. The RQ-21A maximum datalink range is published as 50nm. Were the datalink not the limiting factor, the maximum range would be a function of endurance and airspeed. The RQ-21A maximum endurance observed in a professional test environment was twelve hours with a slick aircraft (mission payloads would reduce this figure).[9] At a nominal 60 KIAS (knots indicated airspeed) and discounting wind effects, an air vehicle could achieve 300nm with a two-hour loiter on-station. (See Figure 1 on next page.)
- Our current UAS employment construct is one crew and one GCS per airborne air vehicle—the traditional "one-to-one" model (the lily pad approach in Figure 1 is actually a "many-to-one" model). While RQ-21A can be left unattended in an orbit or on a route, its functionality is limited to staring at a static location or serving as a basic communications relay node. Should we ever field Group 3 UAS in quantities to justify a "section" or even a "swarm," the resultant manpower and ground footprint would encumber multi-vehicle operations significantly. On the contrary, a single operator, from a single GCS, could launch and recover automated air vehicles every 45 minutes if they did

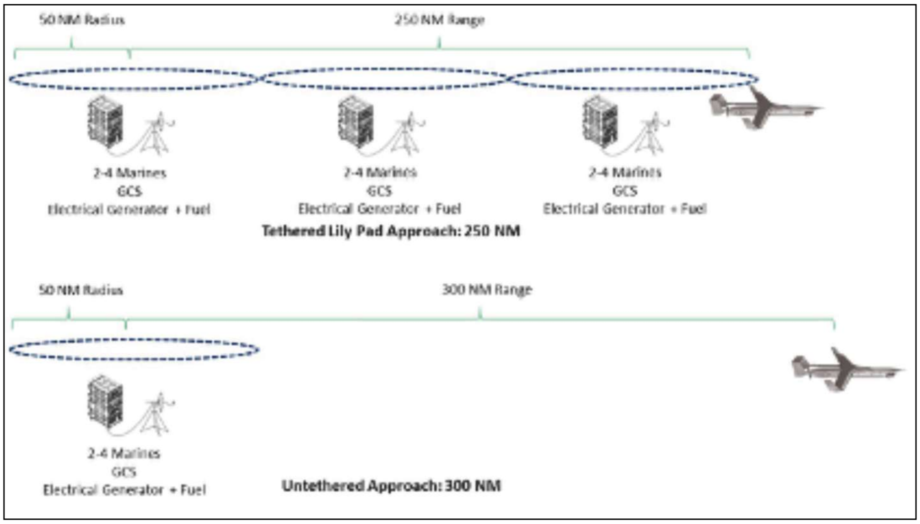

Figure 1.

not require this constant control—the alluring "one-to-many" model. True persistence is possible with a portion of the footprint.

Drawbacks:

- From the dawn of aviation photography until the early 21st century, the preponderance of tactical imagery has required analysts to wait a number of hours, or even days, to receive the sensor product. Satellite collections had long tasking cycles, and aerial imagery required the aircraft to land before pulling the tapes. It was the advent of datalinks and networks that set the realtime paradigm. We grew accustomed to the instant gratification of tasking a sensor to a specific location and being rewarded with a live feed. Without a constant link from operator to sensor to consumer, we revert to our former state of delayed gratification. If constant instantaneous feedback is a true operational requirement on a specific mission, then an untethered flight mode may not be the appropriate tool.
- When eliminating realtime inputs, we are also minimizing our ability to re-task the sensor. This is akin to the archaic method of launching an asset, with specific instructions, unable to recall or re-task it (ala World War II long-range bombers). In other words, we would need to commit to a specific mission for the asset. This runs contrary to the dynamic collections requirements sometimes found in the modern battlespace, which are facilitated by the convenience of communications superiority.
- Until affordable onboard artificial intelligence is scaled to a Group 3 form factor, we should assume that an automated air vehicle will be generally unresponsive to unforeseen events. In essence, it will be a drone. "If-Then" logic can cover simple events—system failures, winds limits, and fuel states. We should not expect onboard advanced target recognition or threat sensing to be a budgetary reality for a Group 3 platform for the next five years.
- Since the air vehicle will only respond to events through its programmed logic, it may not recognize and respond to degrading system performance or weather impacts. If it suffers catastrophic failure, it may have no means to inform the operator. As such, we must prepare for higher attrition rates and accepting a lost asset without explanation. Our concept of air vehicles will approach that of expendable or non-recoverable equipment, akin to munitions and satellites.

SUAS/STUAS Implementation

Since the *Marine Aviation Plan*[10] envisions RQ-21A to be a MAGTF asset through circa 2026, moderate automation upgrade investments are advisable as proverbial stepping stones to subsequent platforms. The narrow autonomy designed for specific mission tasks should be linked together by a general automation that conditionally replaces realtime human input. Consider the following near-term proposals as applying to RQ-21A, and the ensuing mid-term/long-term proposals as being applicable to follow-on UAS in Groups 1-4. This presents a phased approach to capability growth using high technology readiness level (TRL) concepts.

Near-term (two to five years):

These proposals give RQ-21A a new and tailorable LOA 7-9 capability outside LOS range while retaining its current functionality inside LOS. The vision is that the operator programs specific tasking, and the machine returns in-mission feedback by exception (subject to link restoration logic). There is no requirement for onboard autonomy beyond what already exists. Mission tasking is to collect multisensory information on defined locations. The end state is to sustainably execute multisensor reconnaissance at a range of 300nm in a spectrum-contested environment.

• Install a solid state hard drive in the payload bay. This hard drive is used to record sensor products at preprogrammed trigger points and sample rates (snapshots versus full sensor streams), defined by time or location. The data is cached for download to the ground station via link restoration or physical post-flight extraction (ala heads-up display [HUD] tapes).

• Implement an automation mission-planning utility in the GCS and payload control stations as plug-ins. Current software allows the operator to pre-build routes and sensor points of interest (targets). The new proposed utility should expand to include the following items:

  ❍ Datalink disestablishment/restoration logic (time, location, or condition-based).

  ❍ Sensor patterns, to include camera mode, zoom level, and slew rate (in the case of the electro-optical/infrared sensor), should allow the air vehicle flight profile to be slaved to the sensor point of interest.

  ❍ Logic triggers to transition sequentially through flight routes or sensor patterns.

  ❍ Selectable faults/failures or other conditions that trigger return-home behavior.

• Simulation features to “fly” the programmed mission in a simulated environment (at various simulation speeds), with ability to induce logic trigger conditions such as time or aircraft emergencies. This supports training and mission rehearsals.

• Add an automated flight mode; the mission computer enters and exits this mode upon hitting the triggers programmed into the mission plan. The air vehicle goes EMCON but will still receive uplink commands from the GCS when in range.

• Add a live automation training mode; this mode allows the air vehicle to execute its programmed automated mission while still receiving uplink commands and transmitting telemetry for monitoring. It is for training use where Federal Aviation Administration and range regulations prohibit a deliberate lost link (which will probably be most U.S. airspace for the foreseeable future).

• Implement a mission replay utility; this uses the air vehicle’s telemetry logs, automation logic logs, and all recorded sensor products to replay the mission at selectable speeds. It reconstructs the mission to facilitate debrief, analysis of logic triggers, and information reporting.

I illustrate this concept by giving a junior pilot the following instructions:

> Fly to location X, record imagery of locations A, B, and C, and then return to the release point at location Z to downlink the imagery to me, and await further instructions.

Mid-term (five to ten years). These proposals give future Group 1-4 a tailorable LOA 5-9 capability both with and without datalink connectivity. The vision is that the operator programs specific tasking with branch plans or contingency options, triggered by logical flags. There is a basic onboard artificial intelligence requirement for object recognition and sensory interpretation. Mission tasking is to collect multisensory information on specified targets, and selectively transmit information to friendly forces. The end state is to sustainably execute multisensor reconnaissance with limited re-tasking at a range of 300nm-plus in a spectrum-contested environment.

• Migrate the automation mission-planning utility to the Joint Mission Planning System (or its successor) to be easily adapted to multiple systems through platform modules. In addition to those previously mentioned, it should include the following items:

  ❍ Tasked target types, with recognition features from a machine vision library, includes behavioral patterns and EM energy signatures.

  ❍ Logic triggers for burst transmissions (own-ship telemetry, snapshots, or live/recorded sensor data).

  ❍ Logic triggers to transition between flight routes or sensor patterns based on sensor inputs.

  ❍ Conditions requiring operator approval/rejection of autonomous behavior or target classification.

• Integrate low-cost, low-throughput BLOS datalinks for sporadic burst transmissions.

• Implement onboard sensor cross-cueing.

• Integrate onboard machine vision with the decision tree (“If-Then” logic), allowing sensor inputs to trigger flight or sensor profile transitions.

• Improve the mission replay utility to include explanations of all autonomous decisions made.

I illustrate this concept by giving an experienced pilot the following instruc-

RQ-21A recovery following flight during Weapons and Tactics Instructor Course. *(Photo by Cpl Adaezia Chavez.)*

tions: "Fly between locations X and Y, searching for targets of type A and B. If you detect target behavior that matches the library, then abandon the search and focus collections on this target for two hours, while transmitting target location to me once every five minutes. Otherwise, if no targets matching this type are detected within six hours, then return to the release point at location Z and await further instructions."

Long-term (ten to twenty years). These proposals give future Group 1-4 a tailorable LOA 5-9 capability both with and without datalink connectivity. The vision is that the operator programs general tasking with contingency options. There is a robust onboard artificial intelligence requirement to dynamically generate flight plans and sensor patterns, recognize objects and behavior, and make decisions based on a desired outcome. Mission tasking is to collect multisensory information on a force or region, employ a non-lethal effect, and selectively transmit information to friendly forces. The end state is to sustainably execute dynamic multirole missions, at a range of 300nm-plus in a spectrum contested environment.

- Improve upon autonomy mission-planning utilities to include the following items:
  - Airspace coordinating measures, to include minimum risk routes, no-fly areas, and threat zones.
  - Description of enemy forces or facilities that qualify as prioritized targets.
  - Desired effect on each target type (infrared pointer mark, electronic attack, etc.).
- Integrate onboard sensor fusion with the decision tree.
- Implement capability to automatically publish target tracks to tactical datalinks.
- Develop onboard measure-of-effectiveness recognition for lethal and non-lethal effects.

I illustrate this concept by giving a seasoned pilot the following instructions:

> Fly to region X, adjusting your flight profile to mitigate threats that you either detect yourself or receive from a friendly asset along the way. If you detect a threat, disseminate a track to friendly forces. Once established in region X, search for target types J, K, and L for three hours. At time T, select the highest priority target you detected, and employ effect FX against it for one hour, or until otherwise directed. Resume your search with all flight time remaining. Return to base with a minimum 30-minute fuel reserve.

Support to MAGTF Missions

This section explores how an untethered UAS could support the MAGTF through the six functions of Marine aviation during the next five years. It will be some time before autonomous systems can integrate seamlessly into complex airspace (even our current teleoperated STUAS struggle with this), so my assumption is that these missions will primarily be conducted in an environment devoid of legacy (manned) aircraft, or otherwise with compensatory measures in place.

Air reconnaissance. Air reconnaissance is the most basic, and arguably most valuable, mission our UAS support. In an untethered mode, its ability to support forces conducting realtime operations may be inferior to a more human touch. Rather, I see automated air reconnaissance missions as being of primary value in advance of an operation or general battlespace awareness. Initial use cases include route reconnaissance with change detection, wide-area multisensor mapping, 3D imaging of terrain and facilities, long-duration staring surveillance, and target location. Follow-on advancements open up target tracking and early warning.

Electronic warfare (EW). EW capabilities in Group 3 UAS are generally confined to EW support (ES) payloads at this time, as electrical power available is a limiting factor for Electronic Attack. In an automated mode, they can support the ES mission through collecting large area spectrum survey or focused collections on specific emitter types for signals intelligence exploitation. Future iterations can facilitate sensor cross-cueing.

Miniature electronic attack payloads with limited capability are emerging for platforms in this category. Through autonomy, they may be programmed to interfere on a specific range of frequencies at specified times/locations and, eventually, have the ability to detect and react to a specific emitter. Low power output can be partially mitigated by short standoff ranges.

Offensive air support. I am personally not an advocate for arming UAS, and am vehemently opposed to the notion of an autonomous kinetic engagement. Lethal attacks should be a very human action, and taking a life is meant to be somewhat challenging. I can, however, see the utility in an air vehicle searching a large area for a specific target and providing the operator (or other external entity) a weapons engagement solution.

Let us relate this to the dynamic targeting cycle: the find, fix, track, and assess steps can be largely delegated to a machine. Lethal targeting and engagement should be conducted by humans, with decision support coming from a machine.

Anti-air warfare (AAW). While Group 3 UAS are not likely to emerge victorious in an air-to-air engagement, they can still perform some useful AAW work. As referenced in the electronic warfare section, a UAS of this size can conduct limited suppression of enemy air defense or integrated air defense system disruption/stimulation. In a more disposable role, a single air vehicle could effectively neutralize an enemy airfield for a short duration by overtly orbiting over the departure end of the runway and intruding on air traffic control frequencies (think of the chaos this would induce at our own airfields!).

Assault support. A fixed-wing Group 3 UAS is not likely to deliver cargo; however, an automated vertical takeoff and landing (VTOL) UAS could employ this capability with great efficiency. The relatively mundane task of transporting material between two sites is a valid use case and has been demonstrated in a variety of venues. This is not to say that fixed-wing UAS cannot support assault support missions: there is still value in landing/drop zone survey, detached escort, and support to personnel recovery using methods described in previous paragraphs. Take automation one step further: envision loading a fleet of VTOL air vehicles with sustainment kits (water, ammunition, etc.) and sending them on their delivery missions before the resupply request is even submitted. Drop zone location and time is updated in-flight by the recipient (since it may be unknown at the time of launch).

Control of aircraft and missiles (C3). When used as a communications or network node, an automated Group 3 UAS could meaningfully enhance our MAGTF C3 structure. Replace every tactical retransmission site and communications balloon with a UAS orbit. If we add tactical datalink or mesh network features to these platforms, the options expand even further. Today's tactical air control (airborne) and direct air support center (airborne) qualifications could become obsolete when our C2 organizations are able to extend their virtual presence through the battlespace via digital datalinks.

Considerations

It is important to take a holistic view of autonomy and its implications on the force. The equipment is only a portion of the challenge; there are plenty of changes to our thought processes and supporting infrastructure to address before we can effectively employ such a tool.

Tactics, techniques and procedures. We have developed a multitude of control measures, in the forms of airspace coordinating measures and fire support coordination measures, to facilitate combined arms. By introducing a new family of warfighting assets (autonomous UAS), we must also develop a new class of control measures to support C2. These measures should include routing corridors, coordination lines, and operating areas that permit or restrict autonomous operations based on the level of autonomy being employed. We have fire support coordination lines that allow surface engagement with no coordination required; the same principle should apply to an autonomous air vehicle (no datalink required beyond a certain line). The goal should be to restrict autonomous operations as necessary to facilitate deconfliction but also be as permissive as possible to preserve effectiveness. Restricted operating zones are historic artifacts and not a viable solution during our next major conflict.

I also assert that the decision on the appropriate level of autonomy should be left to the operator, not the tasker. The air tasking order provides a specific objective, and the tasked organization selects the most appropriate method to accomplish it (subject to the control measures in place). Some tasks involving dynamic decisions and realtime reporting are best left to a human. Other tasks that depend heavily upon post-mission analysis and mundane decision-making lend themselves nicely to autonomous applications.

Personnel. Current VMU detachments to a MEU are on the order of twenty Marines, about half of which are aircrew. With this number, the detachment is capable of surging to multi-ship operations, but cannot reasonably sustain them. The number of aircrew members required is unlikely to decrease so long as we maintain the requirement to sustain sorties in the traditional (one-to-one or many-to-one) control mode; however, those same eight-ten aircrew would be capable of running simultaneous automated missions (one-to-many) beyond their current sustained capacity. Should we relieve the necessity for constant human control altogether (and accept the operational limitations), this same sortie rate could be sustained by as little as four aircrew.

Training. The ability to optionally-automate aircraft and sensor control does not instantly decrease training requirements. If anything, it actually *increases* the number of training and readiness codes required to qualify in model. Operators would require training to conduct the tasks manually, and subsequent training to program the mission computer to conduct them via automation.

This can be mitigated by eliminating some efficiencies in our current training programs. At the moment, policy requires both officer and enlisted aircrew to train to the standards of an air vehicle operator (AVO) and thus have strikingly similar mission skill progressions. This means that we are manning and training two crew members to employ a system that was designed for a single operator, sporting one set of flight controls. I propose that AVO training should remain relatively unchanged for enlisted operators, and that our officer unmanned aircraft commanders (UACs) become the automation specialists. The UAC role is designed to support planning and supervision, so the major difference from his perspective is whether his commands are

Marines prepare to launch RQ-21A at Yuma, AZ. **(Photo by Cpl Adaezia Chavez.)**

being executed synchronously by a human, or asynchronously by a machine. The concept of using pure flight hours as a metric for occupational proficiency should become obsolete for this occupational field.

The UAS training pipeline closely mirrors legacy naval aviation training in that it instills "aviate, navigate, communicate" skills. I opine that the flight computer already manages the first two fairly well on its own, so we should really be instilling "integrate, communicate, disseminate" skills to become more successful with our current systems. As our systems become less dependent on human input, our skill set should transition to "automate." In fact, automation training could bear a striking resemblance to computer science.

Materiel. As stated in the introduction, my argument is that we do not need to develop custom equipment to begin automating our systems today. The only additional hardware I can foresee for RQ-21A implementation would be a mission computer module, storage drive, and self-destruct or zeroization feature. Software is the major driver in automated systems and has already been developed for similar applications in both military and commercial systems. We should, however, be prepared to procure additional attrition assets because of the inevitable increased consumption rates.

Leadership. The technical challenges associated with automated systems are dwarfed by the challenges encountered on the human terrain. At the lowest echelons, we must learn to release an asset to its own control. (Currently, regulations imply that the AVO cannot even take a biological break with the air vehicle in a static automated orbit—another AVO must fill in.) Tactical information consumers may have to rebuild comfort with detailed planning and tactical patience.

At the organizational leadership levels, we have to shift our perspective of UAS from aircraft to equipment.[11] Words like "mishap" and "safety of flight" should become less common in our vernacular, since we should be less sensitive to loss or damage to unmanned assets. If an autonomous asset fails to return to base, it takes some moral courage to simply move on without explanation.

Conclusion

I hope to have shown how many of Group 3 UAS limitations—range, ground footprint, manning, and EM spectrum dependence—can be mitigated through increased automation. The RQ-21A already includes basic functionality for automated flight control but is in need of a few enhancements before we can cut the cord: onboard sensor control, onboard sensor storage, and the ability to sever the datalink. While this will not be a panacea for winning the battle, it will extend our tools' ability to support the MAGTF. Best of all, it can become available within five years, at a far lower cost than a bespoke program for a generally autonomous platform that removes the human altogether.

As a wise man stated, humans should be informed, involved, and in command; automated systems should be predictable.[12] I would add that they should also be explainable, to build confidence in the system and foster further growth. The proposed implementation plan addresses each of these in turn, allowing the human to tailor the level of involvement to the mission and operating environment while also receiving feedback on the machine's decisions.

MCDP 1 tells us that we must strive to improve our warfighting hardware, along with its tactical, operational, and strategic usage to maximize our own capabilities and to counteract our enemy's.[13] The build-up of automated systems represents the next logical generation of the tools that we bring to battle. Rather than wait for an evolutionary leap, we must begin transforming our legacy systems, today. Waiting for industry to deliver an elegant solution will be too late. Finally, we must collectively embrace the technological change and adapt our frames of reference in order to maintain our warfighting edge. This is our leadership's intent, and it is time for us to execute.

USMC

Notes

1. James N. Mattis, *Summary of the 2018 National Defense Strategy of the United States of America*, (Washington, DC: 2018).

2. James Geurts, *Department of the Navy Unmanned Systems Goals*, (Washington, DC: 2018).

3. Gen David H. Berger, *38th Commandant of the Marine Corps Commandant's Planning Guidance*, (Washington DC: 2019).

4. LtGen Steven Rudder, *Marine Aviation Plan 2019*, (Washington, DC: 2019).

5. CPG.

6. Ibid.

7. Thomas Sheridan, and William Verplank, *Human and Computer Control of Undersea Teleoperators*, (Cambridge, MA: Massachusetts Institute of Technology, 1978).

8. My apologies to UAS aircrew that are offended by the word "operator"; it is a more appropriate term in the context described.

9. Commander Operational Test & Evaluation Force, *RQ-21A OT-C1 Final Report*, (Norfolk, VA: 2015). This particular test did not attempt to reach fuel starvation. Maximum endurance was previously projected to be in excess of sixteen hours (NAWCAD, *Land-Based Test and Evaluation of the RQ-21A STUAS AV and LRE,* [Patuxent River, MD: 2015]). Additionally, there has been one Fleet observation of eighteen hours aloft before fuel starvation. Twelve hours is used in this article as a conservative figure; calculations suggest that 420nm range with two-hours on station may be attainable when untethered.

10. *Marine Aviation Plan 2019.*

11. My apologies to UAS aircrew that are offended that an air vehicle be considered differently than a manned aircraft.

12. Charles Billings, *Human-centered Aviation Automation: Principles and Guidelines*, (Moffet Field, CA: Ames Research Center, 1996).

13. Headquarters Marine Corps, *MCDP 1, Warfighting*, (Washington, DC: 1997).