(Working Title)

sUAS: A STARTER MANUAL

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Foreword

This is an incomplete starter manual for winning in combat with small unmanned aerial systems (sUAS). Recent conflicts around the world—in Syria, the Caucuses, Ethiopia, and Ukraine—have made it clear, from the tactical to strategic levels and in thousands of high-definition videos, that these systems currently offer significant lethal advantages to those who use them. Even greater advantages clearly go to those who continually and efficiently adapt existing systems by improving their hardware, software, and tactics for employment. Given the current state of sUAS integration in the Marine Corps, we know that we cannot continue to wait for perfect top-down solutions later. We must prepare now to use best what we currently have—just as our enemies are doing. This race shall go to the swift.

As a how-to guide, this document aims to provide Marines with some simple, actionable information for fighting with and against sUAS today. As an *incomplete* how-to guide, it provides a set of starting points, and not much more. We share it now, knowing that the day we might consider this guide "complete," it will be obsolete. And while we hope that some of the discussions and methods here inform future Service and/or Joint operating procedures, we're more energized by the likelihood that they'll be greatly improved by those who read them today and test them tomorrow. Such is the pace we must keep.

Developing anything new is usually a team effort, and the methods here are no exception. First and above all, we must credit the impressive—and for us, action-spurring—innovations in this area by the people of Ukraine. We also gratefully acknowledge the contributions to date by the teams at Electronics Maintenance Company, 1st Maintenance Battalion; 3d Low Altitude Air Defense Battalion; 75th Ranger Regiment; the U.S. Army's 1st Battalion, 19th Infantry Regiment (Infantry Mortar Leader Course); the Marine Corps Schools of Infantry East and West; 2d and 3d Battalions, 5th Marines; and many dedicated leaders in 1st Marine Division and I MEF. This document is merely a rough summary of a small portion of their efforts. Any missteps here, though, are our own. We are attempting to sprint over uneven ground.

To the reader: You, too, are now a runner in this race. Here is the baton.

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Introduction

This document develops a few principles and proposes several new tactics, techniques, and procedures (TTPs) for sUAS integration and employment. It is not intended as a general reference on broader aspects of sUAS manning, training, planning or employment, and the TTPs proposed here remain to be more-widely validated, adopted, and codified as standard for Fleet Marine Force (FMF) operations. What this document does do, however, is hopefully provide Marines with a few promising leads for maximizing the lethal potential of current program-of-record (POR) sUAS and CUAS equipment.

Section 1 begins with a discussion of longstanding principles for aviation integration and an overview of current airspace control measures (ACMs) applicable to sUAS. It proceeds with proposals for several new ACMs that could significantly improve sUAS integration with manned aviation and surface fires.

Section 2 presents a new method for using sUAS in a forward observer (FO) capability. Called sUAS Direct Alignment, the method may be employed with all current POR sUAS, requires minimal additional training, and does not rely on any additional software beyond already-fielded digital mapping tools such as KILSWITCH or TAK. In tests of different methods performed with the U.S. Army Infantry Mortar Leader Course at Fort Moore, GA in July and August 2023, the sUAS Direct Alignment method consistently outperformed others in terms of initial accuracy, time between adjustments, and number of adjustments needed. The section provides step-by-step instructions for how to conduct a call for fire (CFF) with this method.

Section 3 provides instructions for adapting current SkyRaider systems to deliver lethal munitions and other payloads. The section provides a link to an online repository of 3D-printable payload adapter blueprints. With these blueprints, Marines can immediately equip their SkyRaider systems to conduct attacks and aerial deliveries. The section also proposes a new, five-line request format for sUAS payload delivery missions. These techniques were developed between late 2022 and 2023 and tested during force-on-force and live-fire exercises at the Mountain Warfare Training Center (MWTC), Marine Air Ground Combat Center (MCAGCC), and Camp Pendleton, CA.

Section 4 provides a general discussion of counter-UAS techniques, but with a focus on a several key, sometimes counterintuitive lessons learned regarding dispersion, camouflage, and weather considerations. Most importantly, this section also seeks to introduce Marines to some potent CUAS tools that are available in their MEFs right now: the AN/TPQ-49 lightweight counter-mortar radar (LCMR) and the Modi II counter-improvised explosive device (CIED) system. While neither one of these systems was originally designed for the CUAS fight, they may be readily adapted for it in place of sufficient quantities of dedicated systems. These adaptations were tested and validated aboard Camp Pendleton in mid-2023.

Lastly, the document concludes with a proposed way ahead: a list of some promising leads for continued TTP development and equipment adaptations. These ideas offer possible projects that Marines and their leaders can commence today. No doubt it is only a partial list, but it represents areas where the small, incremental changes presented in the preceding sections might be advanced into larger, lasting innovations.

1. sUAS Air and Surface Deconfliction

There are currently three main impediments to better integrating sUAS with aviation operations and fires: lack of systems, lack of professionalized operators, and lack of commonly accepted deconfliction methods. All three shortfalls reinforce each other, but there is simply no reason why units cannot start practicing safe and effective integration of sUAS with supporting aviation and fires right now, using existing deconfliction methods. Where these methods come up short, adaptations must be made. This section therefore also proposes several additional, sUAS-specific deconfliction methods; if adopted by the FMF, they could facilitate even greater integration of sUAS with manned aircraft and fires.

Marine Corps and Joint TTPs provide long-standing methods for procedural deconfliction by **altitude**, **lateral separation**, and **time**. [1] In general, altitude deconfliction with other UAS and manned aircraft is preferred because it is least restrictive in terms of effective sUAS employment, particularly with limited sensor ranges and flight times. Where lateral deconfliction is necessary, these limitations are likely to drive commanders to seek relatively narrow separation schemes. But whether integrated through altitude or lateral deconfliction schemes, sUAS operators must be very proficient—there can be no doubt in their understanding and abilities—with maintaining strict compliance with what are called airspace control measures (ACMs).

This document proposes the following as key control measures (procedural controls) and other types of restrictions (normally applied during terminal controls) that all sUAS operators and planners should be familiar with. New ACMs proposed here should be tested, validated and/or refined prior to wider adoption.

Airspace Control Measures

Use of ACMs for sUAS allows the MAGTF to maintain its preference, in line with its airspace control capabilities and our warfighting philosophy, for a blend of procedural and, where necessary, terminal (positive) control methods in support of our ground forces.[2] Procedural control requires that all aviation assets, including sUAS, understand and adhere to established and promulgated procedures and control measures, including fire support control measures (FSCMs).

Wherever possible, ACMs for sUAS should be tied to recognizable terrain features. This principle results from the current configurations of most sUAS control systems, which lack the ability to receive and integrate digital airspace overlays. Identifiable terrain features allow sUAS operators to spend less time checking their system's current grid position against another map or tablet, and also help mitigate the effects of enemy GPS jamming or spoofing. As sUAS with digital overlay capabilities and more-resilient GPS systems are fielded, this principle may become anachronistic—but for most sUAS systems in the hands of Marines now, using recognizable terrain features is highly recommended.

Coordinating Altitude (CA), Coordinating Level (CL), and Coordinating Height (CH)

[1] See Joint Publication 3-52 *Joint Airspace Control*.

[2] For a discussion of positive versus procedural control methods, see MCWP 3-25 *Control of Aircraft and Missiles*, pp. 3-3 to 3-8.

CAs and CLs are existing Joint ACMs; a CH is a new ACM proposed by this document. A CA provides demarcation between different airspace control elements, while a CL is used to separate fixed-wing (FW) and rotary-wing (RW) aircraft by determining an altitude below which fixed-wing aircraft normally will not fly.[3] The concept for a CH derives from the CL: it provides an altitude below which RW aircraft normally will not fly (unless coordinated through other ACMs and/or terminal control) in order to provide deconflicted airspace for sUAS. A CH established at 400ft above ground level (AGL), for example, could provide a "blanket" deconfliction between sUAS and RW across an AO; it could then be superseded, for example, by a RW battle position (BP) with airspace extending down to ground level, and into which sUAS would not be permitted to fly.

Transit Routes (TR) and Checkpoints (CP)

Transit routes may provide both lateral and altitude deconfliction with other aircraft. They may be defined by a single altitude or a vertical interval, and follow pre-planned checkpoints established in the forward area.[4] TRs may not only facilitate aircraft and surface fires deconfliction but also assist with identifying friendly and hostile sUAS. Limited ranges will most likely prevent most sUAS from using TRs designated for larger aircraft; however, in cases where TRs and/or CPs will be shared, a CH should be used for altitude deconfliction. Per current Navy and Marine Corps standard operating procedures, transit routes are named after U.S. state abbreviations (e.g., "VT") and checkpoints belonging to those routes are given successive numbers (e.g., 1,2,3).[5] Checkpoints are depicted on map overlays with a circle.

Restricted Operations Zones (ROZ) and Airspace Coordination Areas (ACAs)

ROZs are airspace reserved for specific activities in which the operations of one or more airspace users are restricted. ROZs may be established either to restrict manned aircraft from operating in close proximity to sUAS—these are called Unmanned Aircraft Areas (UAs)[6]—or to restrict sUAS from entering an area where manned aircraft are operating (for example: assault support pickup zones). Where a CH has not been established, ROZs are often the "standard" solution to sUAS and manned aircraft deconfliction. Experience shows that their constructions, often involving wide lateral deconflictions from other aircraft, tend to reflect air planners' concerns about the ability of sUAS operators to dependably abide by strict procedural controls. The result is often sub-optimal integration of sUAS into overall fires and collections plans.

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[3] JP 3-52, p. III-6.

[4] JP 3-52, p. C-3. Some sUAS planners have proposed *Low-Level* Transit Routes (LLTRs) as a preferred control measure; LLTRs are a subset of TRs, also originally intended for manned aircraft, but are not well defined. Per JP 3-52, LLTRs are "a temporary corridor of defined dimensions established in the forward area to minimize risk to friendly aircraft from friendly air defenses or surface forces" (p. C-3). This definition is, word-for-word, the same definition given to TRs. While the reference does additionally state that LLTRs may be "bi-directional" without specifying the same for TRs, TRs may in fact be bi-directional as well—although this is not recommended for either, and strict altitude deconfliction is required in such cases. Meanwhile, the Marine Corps' principal airspace control reference, MCWP 3-25, includes mention of LLTRs (and not TRs) but never defines them, while NTTP 3-22.5 *USMC Assault Support Tactical SOP (ASTACSOP)* of January 2023 (Change 1, April 2023) mentions neither TRs nor LLTRs but simply refers to "routes." Given the evident ambiguity about how LLTRs actually differ from TRs, this document sticks to the overarching label of TRs.

[5] NTTP 3-22.5, p. 1-9.

[6] JP 3-52, p. C-5.

ACAs, like ROZs, are three-dimension blocks of airspace used for deconfliction, but they are specifically applied in target areas to coordinate high-volume surface fires and close air support (CAS). Deconflicting rotary-wing (RW) and fixed-wing (FW) aircraft from each other and surface fires, they provide areas and altitude blocks for friendly aircraft to safely operate. RW holding areas (HAs) and battle positions (BPs) are common examples in the Marine Corps of informal ACAs. The purpose of ACAs—maximizing integration of air and surface fires in a target area—makes them a better fit for most scenarios requiring sUAS deconfliction. However, as with ROZs, current experience shows that planners often establish overly restrictive ACAs for sUAS, sacrificing sensor integration for wide lateral separations from manned aviation.

With greater professionalization, sUAS operators should be trusted—and expected—to integrate much more closely into shared airspace. The following two proposed ACMs provide a convention for sUAS ACA planning based on RW precedent.

sUAS Loitering Areas (LA) and Task Positions (TP)

These two proposed ACMs are modeled after RW aircraft HAs and BPs. HAs serve to not restrict attack aircraft to specific observation or holding patterns, but to provide airspace away from enemy threats, friendly fires, adjacent units, and intervening terrain so as to allow good observation of the target area.[7] BPs provide similar latitude for aircraft to select optimal firing points and also serve to deconflict with fires and other aircraft. The rationales that underpin these ACMs naturally apply to quadcopter and perhaps other tightly-turning sUAS as well.

LAs in particular may be a very useful ACM for sUAS, since they can be used to position systems out of reach of enemy jamming but close enough to rapidly execute missions in support of ground forces. They may also be used if friendly jamming is known or likely to interfere with friendly sUAS. In that case, the ground force may hold the sUAS in the LA until they can temporarily suspend jamming and allow the friendly sUAS to execute its support from a designated TP.

TPs can similarly simplify the deconfliction of sUAS support with gun-target lines (GTL), friendly ground forces, and other aircraft. They may be particularly useful to position sUAS for overhead surveillance, adjusting rounds, or delivering munitions in battlespace where troops are in close contact and positive (terminal) control by a JTAC is necessary to prevent conflicts with other friendly aircraft.

The establishment of LAs and TPs will differ from HAs and BPs. HAs and BPs are both normally constructed as 2km x 2km squares, with airspace extending from the surface to an established ceiling. This document proposes that for sUAS, LAs and TPs should be much smaller (perhaps 500m x 500m), should include lower ceilings to maintain deconfliction with other aircraft (see: Coordinating Height), and should follow different naming conventions: while HAs are named after women and BPs are named after animals (beginning with snakes), LAs should receive male names and TPs should be named after bugs.

Aerial Contact Point (ACP)

A contact point is a familiar ground tactical control measure (TCM); this document proposes its adaptation as an ACM for use where enemy sUAS are present and friendly sUAS remain unequipped with identification-friend-or-foe (IFF) capabilities. An aerial contact point provides a location and

[7] JP 3-09.3, p. III-85.

altitude for a sUAS to conduct "link up" with supported friendly forces via far/near recognition procedures with the operator and/or system. By proceeding to a planned aerial contact point and holding until "linkup" is confirmed, friendly sUAS may be more easily and confidently identified as such.

Terminal Control Restrictions

In dense and dynamic airspace over a target area, and particularly where friendly forces are in close proximity, procedural controls by themselves will not be sufficient to enable safe and effective integration of multiple aircraft and firing agencies. In such situations, a form of positive control called *terminal* control is required. While generally more restrictive, terminal control methods can actually maximize fires and collections integration on the battlefield. But they also require sUAS operators to strictly maintain reliable communications with on-scene terminal attack controllers, whether Joint Terminal Attack Controllers (JTAC) or Forward Air Controllers (Airborne) (FAC(A)), who are positively controlling aircraft in the forward area.[8] Failure to train and plan for full sUAS integration with the "stack" creates unnecessary risk, prevents optimal integration, and will likely result in wasted resources.

Final Attack Heading (FAH)

Final attack headings may facilitate friend-or-foe recognition of sUAS by ground forces, greatly reduce risk of fratricide by the sUAS operator against friendly positions, mitigate collateral damage, and deconflict sUAS attacks or aerial deliveries from active gun target lines. FAHs should normally be used for sUAS whenever ordnance is being employed. FAHs provide some flexibility to the sUAS operator, allowing the operator to prosecute the target in the best manner possible as long as the system maintains the required degree of restriction in its heading. However, like all restrictions, FAHs should not be used when not required.[9]

Stay-Below / Stay-Above Altitudes

Stay-below altitudes deconflict sUAS operations with other aircraft and/or artillery gun target lines. As with other aircraft, stay-below restrictions should generally not be used to deconflict with mortar fires—although in the case of sUAS, the possibility of mid-air impacts with short rounds may be less concerning. Meanwhile, stay-above altitudes may be used to deconflict one sUAS with other sUAS or, in certain cases (typically only involving FW sUAS), with manned RW aircraft. More commonly, stay-above altitudes may be used to keep sUAS above the vertical ricochet hazards presented by surface munitions such as medium or heavy machineguns.[10]

Stay-Away Distance

Where appropriate altitude separation cannot be achieved, a stay-away distance from a point or defined line (e.g., a northing or easting) may provide necessary deconfliction. The "distance" in some cases may be zero: "stay north of MSR Burlington" is also an example of this type of restriction. However, given

[8] For details on JTAC and FAC(A) responsibilities, see Joint Publication 3-09.3 *Joint Close Air Support*, Ch. V.
[9] JP 3-09.3, p. II-76.
[10] See DA Pamphlet 385-63 *Range Safety* for surface munition vertical hazard distances. Note that the reference expresses these distances in meters, which for sUAS operators will normally necessitate conversion into feet above ground level (AGL).

the limited sensor ranges and flight times of most sUAS, lateral separation is likely to present significant challenges to effective employment and should be avoided if possible.

2. sUAS Direct Alignment for Mortars and Artillery

Current MAGTF indirect fires are limited to the line of sight of the forward observer (FO). Equipped with sUAS, FOs can not only extend targeting ranges for indirect (and direct) fires assets, but also improve their own survivability. The method for sUAS employment presented here, termed sUAS Direct Alignment, also enables FOs and firing agencies to shorten the kill chain while reducing possibilities for error.

A New Type of Fire Mission

sUAS Direct Alignment adjusts fires using a combination of sUAS electro-optical/infrared (EO/IR) sensors and mapping software available throughout the MAGTF. Like traditional direct alignment methods, all adjustments are made with reference to the gun target line (GTL).

Key Benefits of the sUAS Direct Alignment Method

- Minimizes personnel, steps and time required to execute a fire mission when compared to any of the existing conventional call-for-fire (CFF) methods.
- Allows FO actions to be conducted from anywhere within sUAS range, obviating challenging foot movements through restricted terrain and/or areas subject to enemy observation.
- Allows for target acquisition and observation of impacts that would otherwise be unobservable due to terrain masking or defilade.
- In comparison with traditional direct alignment, reduces exposure of the firing agency to line-of-sight observation by the enemy.
- Eliminates several error-producing steps in the traditional CFF process: there is no observer location to plot, **no observer-target (OT) factor to apply**, and **no range correction factors to process**.
- Easily applies to nearly all indirect fire assets, to include machineguns in full or partial defilade.

Key Limitations

- Operating Time: Units must be prepared to rapidly switch between sUAS-assisted and traditional forward observation, given the limited (often less than one hour) endurance of most current sUAS.
- Weather: The sensitivity of most current sUAS to wind and precipitation implies the same as above. Additionally, low cloud cover may also necessitate traditional FO techniques.
- Enemy Observation and Targeting: While sUAS can allow FOs to maintain greater stand-off distance and protection from enemy observation and fires, it can also increase the overall visual, audible, and electromagnetic signatures of friendly forces, potentially cueing enemy collections and targeting capabilities in ways that traditional FO techniques can avoid.
- Airspace Deconfliction: As discussed in the first section, use of sUAS for fire missions may require additional airspace planning as compared with traditional FO employment.
- Training and Sustaining sUAS Operators: While the sUAS Direct Alignment method is simple to execute, it depends on well-trained sUAS operators able to precisely navigate, find/correlate targets, infer grid locations from observed targets and impacts, and operate mapping software. Instruction

time and practical application are needed to acquire these skills; how much will depend on the operator. Units must balance between a desire for as many trained sUAS FOs as possible and their ability to adequately sustain these skills with sufficient training repetitions, ammunition, etc.

Safety Considerations

Until all involved units are proficient in the sUAS Direct Alignment method, firing agencies should check-plot using a plotting board and/or LHMBC to ensure safety of fires. **sUAS Direct Alignment does not eliminate the FDC—the FDC provides check-plotting, and is prepared to resume its normal functions if/when the sUAS is grounded and the FO must return to conventional methods**. However, once units are proficient in sUAS Direct Alignment, check-plotting may also be accomplished with an additional tablet and mapping software—the speed gained will help realize the full benefits of this method.

Required Tools

- **sUAS platform** with EO/IR camera and viewer. Marine Corps-fielded Skydio, SkyRaider, and Puma systems all provide this capability.
- **Tablet or computer** with mapping software that allows users to measure an azimuth and range between two points. KILSWITCH and TAK both have this functionality built-in, with no need for any additional plugins.

Executing sUAS Direct Alignment

The following provides the steps to initiate fires and adjust rounds using the sUAS Direct Alignment method.

Initiating Fires

1. (FO) Identify target location with sUAS platform by one of the following methods.
   - **Laser designator**: Retrieve target location using sUAS laser grid-location capability.
   - **Viewfinder**: Place the sUAS viewfinder reticle pattern over the observed target. The sUAS software uses the system's altitude and angle of observation to estimate the target's grid location.
   - **Terrain association**: Correlate the target's position relative to surrounding terrain in the video feed with an estimated location based on available digital imagery and map data.
   - **Fly-over**: Fly the sUAS directly over target and use the system's reported location at that point as the target location.

For systems without laser designators, a combination of the view-finder and terrain-association methods reliably obtains accurate target and splash locations.[11]

2. (FO) Plot firing agency position and target location in mapping software.

[11] The terrain-association method significantly reduces the risk of errors resulting from inaccurate viewfinder location measurements. These errors are particularly likely to arise when the system is at a significant lateral distance relative to altitude from the target, and/or when the target is located on mountainous or undulating terrain. For a detailed explanation of these sources of error, see 1st Light Armored Reconnaissance Battalion, "1st LAR UAS Program," PowerPoint presentation dated 3 Nov 2017. Available from 1st Light Armored Reconnaissance Battalion by request.

3. (FO) Use the mapping software's "line and bearing tool" or similar functionality to measure an azimuth and range from the firing agency to target.

4. (FO) Call for fire with a sUAS Direct Alignment mission, passing the GTL azimuth in mils grid and range to target (from firing agency) in meters.

5. (Firing Agency) Set appropriate referred deflection on sights based on the azimuth of fire. Set appropriate elevation/charge data based on transmitted range to target and calculations provided by ammunition-specific Tabulated Firing Tables (TFTs) or "whiz wheel."

Adjusting Fires

6. (FO) Maintain the sUAS in a position to maximize viewing area around the target.

7. (FO) Observe splash and use one or more of the target/splash-location methods listed in **Step 1** to measure a grid for the splash.

8. (FO) Use the mapping software's line-and-bearing tool to measure the azimuth and range from the firing agency to the **splash**.

9. (FO) Send the correction to the firing agency. (See example below for calculations.)

10. (Firing Agency) Apply the mil correction to the gunsights and adjust elevation/charge data to add or subtract range in meters.

Example **sUAS Direct Alignment Fire Mission**

The FO locates a ZBL-09, plots it in relation to the firing agency (FA) location (Figure 1)*, and transmits a CFF.*

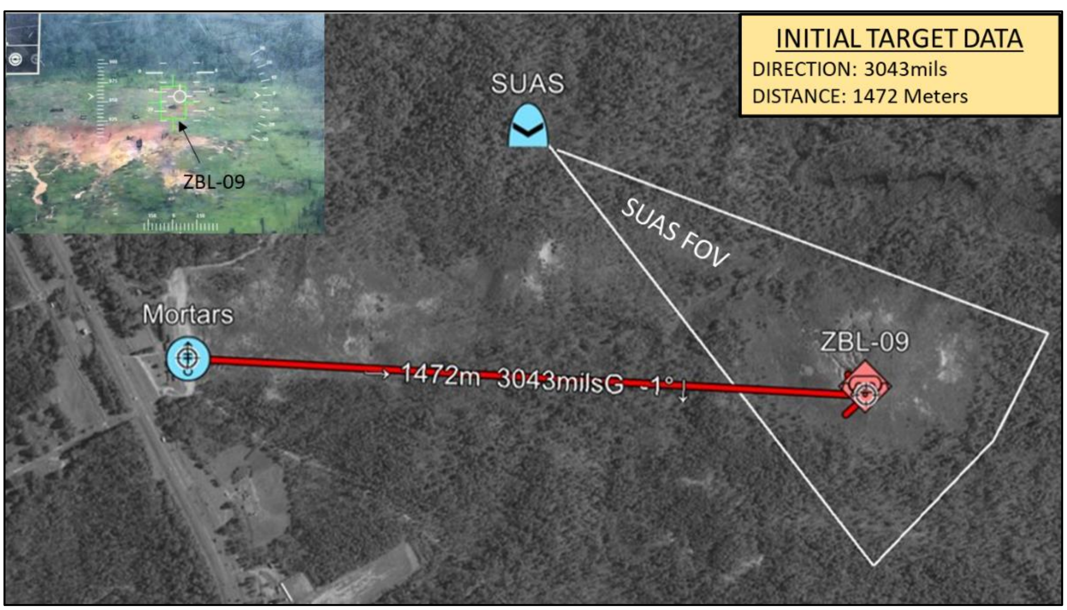

Figure 1 - Calculation of initial target data using digital line-and-bearing tool.

Line 1 **FO:** "Red Cloud, this is Seminole, sUAS Direct Alignment, over."
FA: "Seminole, this is Red Cloud, sUAS Direct Alignment, out."

Line 2 **FO:** "Direction 3043 mils grid, Range 1472 meters, over."
FA: "Direction 3043 mils grid, Range 1472 meters, out."

Line 3 **FO:** "Enemy armored personnel carrier with dismounts in the open, over."
FA: "Enemy armored personnel carrier with dismounts in the open, out."

MTO **FA:** "Red Cloud, 4 guns, 1 round in adjust, 3 rounds in effect. Target number AD2001."

The initial adjust round lands left and short of the target (Figure 2)*. The FO calculates the correction and transmits it to the FA.*

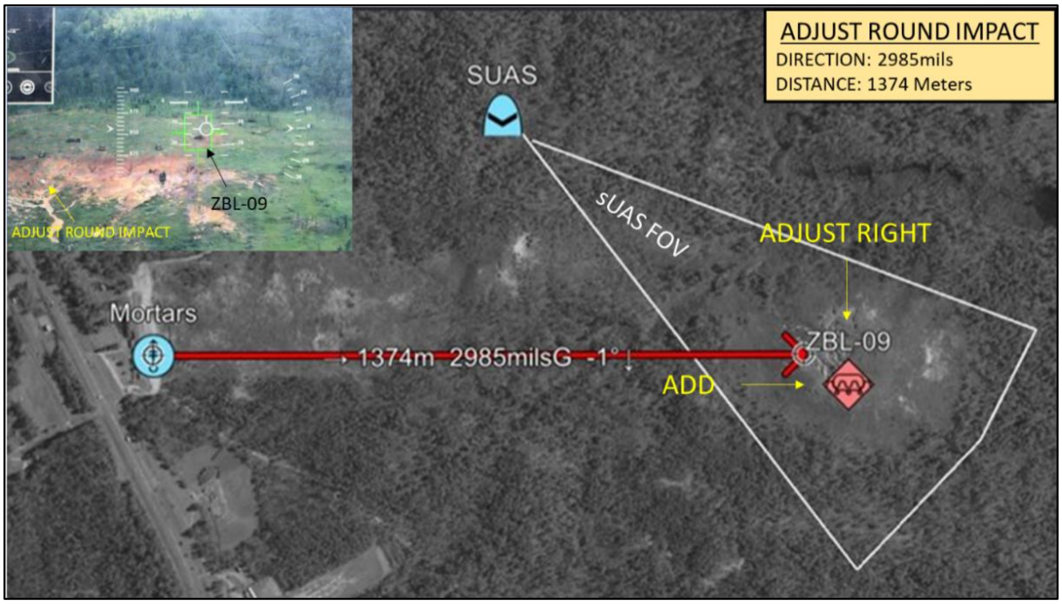

Figure 2 - Calculation of round adjustment using digital line-and-bearing tool.

The FO calculates the left/right correction by taking the difference, in mils grid, between 1) the measured azimuth from the firing agency to the target, and 2) the azimuth from the firing agency to the splash.

Azimuth to Target – Azimuth to Splash = Left/Right Correction
3043 mils – 2985 mils = 58 mils

The FO then calculates the add/drop correction by taking the difference in meters from the firing agency's range-to-target and range-to-splash.

Range to Target – Range to Splash = Add/Drop Correction
1472 meters – 1374 meters = 98 meters

Corrections are transmitted to the firing agency in exact mils grid and nearest 25 meters. Units are always specified to avoid confusion with other types of fire missions.

Correction **FO:** "Target number AD2001, RIGHT 58 mils, ADD 100 meters, over."

The firing agency applies the correction to their referred deflection and elevation/charge data.

The adjust process is repeated until fire-for-effect (FFE) criteria is met.

End-of-mission data is transmitted the same as with other types of fire missions.

3. sUAS Payload Delivery

Marines can deliver critical supplies, obscure enemy observation, mark targets, and attack enemy formations with the sUAS they have **right now**. Some sUAS, like the SkyRaider, can hold small payloads and release them upon receipt of the operator's command. Payload attachment typically involves securing one or more objects with a sling, attached to a hook on the underside of the system. Release involves motorized rotation of the hook, causing the sling to slip from the hook and the attached payload to fall. Payload options are thus constrained by shape, weight, ability to securely sling to the hook, and suitability for dropping. They may include objects like batteries or magazines (resupply of friendly forces), smoke grenades (for obscuration or marking), incendiaries (destruction of enemy equipment), and fragmentation grenades (destruction of enemy personnel).

The SkyRaider platform, combined with a 3D-printed carriage and delivery system called the SkyRaider Payload and Marking Attachment (SPAM-A), provides commanders immediate access to these capabilities. This section discusses current SPAM-A options, proposes a single request format for sUAS payload delivery missions, and presents validated procedures for attacking targets with M67 grenades.

SkyRaider Payload and Marking Attachment (SPAM-A)

The SPAM-A is 3D-printed, five-cylinder sleeve adapter that mounts via zip-ties to the legs of the SkyRaider (Figure 3). Each cylinder has a trap door on the bottom that is actuated by a center plunger connected to the SkyRaider's "drop claw" hook on the belly of the aircraft. Once the drop claw is opened, the plunger is released, causing the trap doors to open and allowing the payloads to drop. Upon exit from the cylinders, the safety lever on each munition will release and activate the fuse.

Current SPAM-A digital blueprints can be downloaded from the "sUAS Team" Marine Corps SharePoint site at [https://usmc.sharepoint-mil.us/:f:/t/sUAS/EqaxpeWNxA9Ovj1ZGEiMz2UBgIerdPzLU3v0XFgiNCVCcA?e=XwDL1H].

Figure 3 - SkyRaider with SPAM-A and M18 smoke grenades

SPAM-A Payloads

Most lever-activated munitions within the small arms inventory will fit the SPAM-A. They include:

- M18 Smoke Grenades
- M67 Fragmentation Grenades (and "Blue Body" practice grenades)
- Incendiary Grenades
- CS Canisters

- Flash Bangs
- Tennis Balls (for counter-sUAS training)

Performance Characteristics

The SPAM-A with inserted payloads reduces the SkyRaider's endurance to approximately 15-18 minutes, depending on winds, elevation, and air temperature. This flight time allows for an estimated 2,000-meter operating range if a straight line is followed from launch to target. ACMs and other restrictions may significantly reduce the effective range.

Loading the SPAM-A

Loading consists of inserting the munition into each cylinder and then removing preliminary safeties such as thumb clips and pull pins. Each cylinder keeps the lever of its inserted munition from extending far enough away to activate the time fuse. Loading smoke grenades upside-down is preferred due to the length of the lever as it may "catch" on the interior of the cylinder and prevent the munition from dropping freely when released. Fragmentation grenades should be loaded upright to enable manipulation of safety mechanisms.

Special care must be taken when loading fragmentation, incendiary, or CS munitions. **The following provides precise steps for loading and operating with M67 grenades.**

1. Construct a loading area (Figure 4) and a standoff position. The loading area consists of a sandbag parapet built in accordance with standard specifications[12] to protect personnel in the event of a premature release. The standoff position is located at least 150 meters from the launch point for single grenades, and 300 meters for multiple-grenade payloads.[13] Drops with multiple grenades should be conducted in a dedicated impact area to account for the possibility that a dud is kicked out and unable to be located.

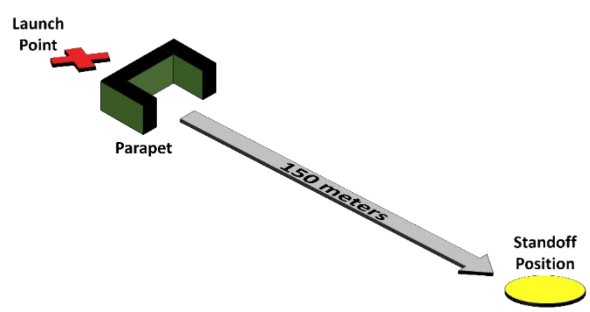

Figure 4 - M67 Loading area and standoff position.

2. Configure the SkyRaider: attach the SPAM-A and place the plunger in the "up/closed" position with the system's drop claw also up/closed.

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[12] See DA Pamphlet 385-63 *Range Safety* of Apr 2014, p. 46. The parapet must be at least 1.5m high and 0.5m thick.

[13] Per DA Pamphlet 385-63, pp. 46-48, 150m is the safe distance for unprotected personnel *for a single grenade*. With multiple grenades, one or more grenades may fail to detonate with the others. Blasts from detonating grenades could then throw those grenades to points where now their fragmentation patterns present risks to personnel beyond the original 150m distance from the drop point.

3. Emplace the SkyRaider with SPAM-A atop a mounting platform (Figure 5) that will hold the plunger in the up/closed position even if the drop claw is inadvertently rotated to down/open. Units may design their own mounting platforms with available materials. Based on the current SPAM-A design, the mounting platform should be 4.5 inches in height.

Figure 5 - SPAM-A mounting platform concept (shown in blue)

4. Crimp with a Leatherman (but do NOT remove) the ends of the grenade pins to reduce the force required to pull them out. The spring action of the spoon will hold the pin in place, but care must be taken to keep them inserted until after the following two steps.
5. Remove the thumb clip from each grenade.
6. Insert each grenade into one of the cylinders, observing for a smooth slide. If the grenade does not slide smoothly in the cylinder, do not use that cylinder—the grenade may fail to drop when released. Mark the cylinder for later sanding and/or cleaning.
7. For each grenade: remove the pin and observe to ensure the spoon is retained in place by the cylinder. In the remote chance that the spoon is not retained, take immediate cover in the parapet as the grenade will now detonate.
8. Once all pins are removed, move back to the standoff position.
9. Launch the sUAS and deliver the payload.

Figure 6 – Images of SkyRaider (left image, yellow circle) attacks with fragmentation grenades at Camp Pendleton, CA on 29 September 2023. The sUAS operator repeatedly delivered M67s to a 10-digit grid in the northwest corner of the trench (right two images).

Safety Considerations

Release Failures: If any grenades fail to fall from their cylinder on release, the sUAS operator will attempt to dislodge them by making small, quick, repeated adjustments to the system's hovering location. If any grenades still fail to release, the operator will land the sUAS at its original takeoff point next to the loading area. EOD will then render safe any munition that fails to release.

Loss of Link: Often it will be best to program the sUAS to return to its launch position upon loss of link. However, operators should note that most sUAS will return via the most direct route, which may violate established ACMs and put other aircraft and ground forces at risk. An alternative is to program an aerial contact point, where the sUAS may hover until the operator can re-establish link. Note, however, that once the system's batteries lose charge, most sUAS will land in that spot.

Friendly Forces: When employing a lethal payload, flight over friendly troops should be avoided. Determining appropriate lateral separation requires consideration of three sources of uncertainty: the probability of incapacitation at a given distance for the munition being carried; the presence of winds and the distance that the munition may be blown during its fall; and the susceptibility of the sUAS to drift/deviate from its assigned route. Given the significant standoff distance (150m) already prescribed by DA Pamphlet 365-63, coupled with the observed reliability with which the SkyRaider follows assigned flight paths, the standard standoff distance of 150m may be used as a minimum safe distance (MSD) for friendly troops off the sUAS transit corridor. Note that this MSD does not account for uncertainty arising from enemy GPS jamming or spoofing.

Employment Considerations

The 4-5 second fuse time of the M67 means that a drop from about 400 feet will result in the grenade detonating momentarily after or before impact with the ground. Higher drops will result in air bursts, which may be less effective. Lower drops will lengthen the time the grenade is on the ground before detonation, which may allow the enemy to seek cover or toss the grenade away.

At 400 feet, the SkyRaider is both highly visible and audible, making M67s less than ideal as an attack munition. However, considering the limited range of the SkyRaider when loaded with grenades, this attack profile may be well suited for forces already closing in on an enemy position. In such cases, the other sights and sounds of battle may help mask the approaching SkyRaider—and integration of other fires should, in Marine Corps combined arms fashion, disrupt the enemy's ability to defeat it.

sUAS Payload Delivery (SPD) Requests

The following provides a standard format for requesting sUAS payload delivery support. While it includes elements of a CAS 9-Line, it may be used for deliveries other than ordnance against enemy positions. Examples include battery resupply and smoke obscuration. This format also differs in that it involves a read-back from the sUAS operator for every line, including all remarks or restrictions.

SPD Missions
- **"Attack"**
- **"Smoke"**
- **"Resupply"**

Line 1: Warning Order

"SkyRaider, this is Apache, sUAS **attack**, over."

"Apache, this is SkyRaider, sUAS attack, out."

Line 2: Location

"Grid: 11SNT 79652 89123, over."

"Grid: 11SNT 79652 89123, over."

Line 3: Description of Target or Drop Location

Examples:	**Attack**:	"Fire team in trench line."
	Resupply:	“Drop on air panel in clearing."
	Smoke:	"Intersection two blocks north of air panel, south of GRG A12."

Line 4: Location of Nearest Friendly Forces

Provided in terms of distance (meters) and direction (cardinal) from drop grid.

"Nearest friendlies: 400 meters Southwest."

Line 5: Remarks and Restrictions

The following remarks and restrictions may be applied:

- **Desired Effects**. Provided to ensure understanding of intent. Examples: "Obscure EN observation west of my position," "Drop grenades into the trench," etc.

- **Payload-on-Coordinate or Payload-on-Target**. With no wind, the SkyRaider can reliably drop payloads onto a 10-digit grid. The requesting force may therefore authorize the operator to adjust the drop location if the target moves. Just as with traditional close air support, Payload-on-Target drops should normally only be executed after the requesting force and the sUAS operator correlate the target with each other.[14]

- **Time on Target** (NET, NLT, At My Command). Timing restrictions may be used to ensure appropriate deconfliction and/or increase the chances of hitting the target.

- **Alternate Signal** for at-my-command releases. Keeping in mind the narrow fields of view of most sUAS, the commander may provide an alternate signal (air panel, etc.) to the sUAS operator in case radio communications fail.

- **Routing Restrictions**. May include **checkpoints**, **HAs** and **BPs**, and **stay-above**, **stay-below**, or **stay-away** restrictions.

- **Estimated Wind Speed and Direction**. Assists the operator in adjusting drop points to account for the effects of wind on the falling munitions.

[14] See Joint Publication 3-09.3 *Joint Close Air Support*, pp. V-33 to V-44 for a detailed discussion on principles and methods for target correlation.

- **Contact Point** for far/near recognition.

- **Actions on Jamming**. Provides instructions to the operator for what to do if sUAS link quality or performance indicates possible enemy jamming. In certain situations, the commander may wish for the sUAS operator to attempt to continue the mission; in others, the commander may direct the operator to abort.

4. Counter-UAS Tools and Techniques

sUAS provide significant advantages to tactical units, but they can be defeated. Methods of defeat include both active and so-called passive measures, although the second label is misleading—there is nothing "passive" about continual setup, teardown, and improvement of camouflage, overhead cover, decoys, etc. While Marines currently lack specialized equipment for the counter-UAS (CUAS) fight, they do have generalized tools that can and must be applied. Surveying those tools, this section discusses the principal passive and active measures that Marines can take right now. Nothing presented here—dispersion, camouflage, thermal masking, radar-tracking, jamming—is new, nor is it exclusive to the sUAS threat. But the suggestions and other considerations provided will hopefully provide a slightly more advanced starting point for units just starting to train against the sUAS threat.

Passive Methods

The ubiquity and flexibility of cheap sUAS will likely always challenge Marines' abilities to defeat them through any set of specialized weapon systems. Therefore, the following passive measures are not simply an "interim" solution; they are and will be our continuing actions for the foreseeable future.

Dispersion

Tactical dispersion has been necessary on the battlefield since the introduction of breech-loading and repeating rifles over 150 years ago. sUAS proliferation doesn't change that, but it does introduce some additional considerations. First, while dispersion may help reduce visual signature to enemy ground forces, it may also actually increase visual signature to passing or loitering enemy sUAS. That's because a widely dispersed force provides more chances, over a larger area, for visual or thermal detection within the system's field of view (FoV). *Dispersion may therefore primarily be a means to limit or slow collections on the size and composition of friendly forces and to protect them against the effects of dropped munitions, rather than a means to avoid outright detection from sUAS*. **Bottom line: if targeting by enemy sUAS is the greatest threat, then use tactical dispersion, but not more than the terrain and vegetation support effective concealment from overhead**.

Visual and Thermal Camouflage

Avoiding detection will usually require some elements of camouflage. Camouflage should make it difficult for enemy sUAS operators to discern the presence of friendly forces through their systems' cameras and video screens. Right now, most sUAS do not operate with timely, reliable automatic object detection/recognition software or services; when they do (they will, soon), our camouflage efforts will simply need to continue adapting to confuse and defeat those algorithms as well. *Currently, the most critical elements of visual signature are color, outline, motion, and heat*. The first three are the traditional focus of camouflage efforts; heat is added to this list because many sUAS carry electro-optical/infrared (EO/IR) cameras that provide the operator a colorized representation of objects' relative thermal radiation levels. For ground forces, only marginal reductions in thermal radiation levels relative to the surrounding environment are usually attainable—human beings are warm-blooded. If thermal radiation cannot be reduced, it must be masked.

Absent special materials, heat can be "masked" from a thermal sensor by placing an object or screen between its source and the sensor. The closer that screen is to the heat source, however, the sooner that screen is likely to absorb and begin emitting heat itself, or to create a buildup of hot air that eventually escapes (and emits) through available openings. **Therefore, individual measures like ponchos and thermal blankets are likely to be most effective only when used for a limited time**, perhaps on-call when enemy sUAS is detected in the area. Longer, continuous use of these measures (e.g., in an observation post) will eventually produce a detectable heat signature wherever hot air escapes (and the heat *shall* escape—or else the individual will cook).

Thermal masking can provide longer-term protection if the screen is placed further away from the heat source. Below the screen, ambient air mixes with hot air near the heat source, producing a temperature gradient that becomes small at or near the screen. When passing sUAS observe the screen, it does not stand out from the surrounding environment. **Standard camouflage netting, properly elevated, can achieve thermal masking even for large heat sources such as vehicles and generators**. Double-layering the netting can also help ensure the sensor cannot see "through" the netting to the heat sources below.

Ground forces on the move will be most challenged to mask their heat signatures. This is where it may be more helpful to consider thermal emissions as a special kind of color, especially because that is how most thermal sensors render those signatures to human operators. With that concept, a tradeoff emerges: it may actually be far more difficult to blend in with the surrounding environment's *thermal* "colors" at night than with its *optical* wavelengths during the day, especially where vegetation could also help mask physical shape. In such scenarios, our inclination to operate at night to avoid detection may actually *increase* our detectability. Meanwhile, warm air during daytime hours may make thermal detection far more challenging, while our personal camouflage might conceal us much better in the visual spectrum against surrounding terrain and vegetation. **Bottom line: ubiquitous thermal sensors force us to reconsider existing adaptions for avoiding purely visual detection**. **Against our prior expectations, it may be easier to avoid detection from most sUAS during the day than at night.**

Physical Protection

The need for protection from overhead fires is nothing new, and existing entrenchment techniques remain valid. However, with sUAS able to precisely target small apertures, modifications to vehicle/turret designs and bunker construction may be necessary. For ground forces conducting temporary halts and not able to entrench with overhead cover, the same camouflage netting used for concealment may also provide some protection against sUAS used to drop simple munitions or conduct one-way attacks. That's because the small sizes and lower velocities of sUAS may limit their abilities to penetrate most netting, providing some limited protection. **To best protect against air-dropped, point-detonating munitions, camouflage netting or protective mesh/wire should be tautly constructed with sufficient slant angles to cause the munition to bounce or roll away from the center and towards the sides of a covered position**. Gaps or droops in the netting will form baskets that simply catch and trap dropped munitions—with unwanted effects.

Active Methods

Air Sentries and Electronic Sensors

The Aviation Combat Element (ACE) currently possesses a limited number of dedicated sUAS detection and recognition systems; at time of writing, the Ground Combat Element (GCE) does not.[15] As part of all local security efforts, ground forces must assign Marines to use their eyes and ears to observe for sUAS in nearby and overhead airspace. Just as important, units must also establish and train to far/near recognition procedures to discriminate enemy sUAS from friendly systems.

Beyond human observation, **the GCE also possesses another tool that can be adapted for the CUAS fight: AN/TPQ-49 LCMRs**. These relatively small, vehicle-mobile radars are fielded to artillery battalions at the battery level. While intended for identifying the points of origin (POOs) of enemy mortar attacks, testing at Camp Pendleton has verified that these radars can also easily detect small aerial systems and be used to identify their altitudes and courses. This information, in turn, can support rapid estimates of launch points and intended targets, enabling both defensive and offensive responses.

While air sentries and radars by themselves do not actively defeat sUAS, they provide forces conducting active measures the reaction times needed to be successful. Units should therefore incorporate all available early-warning capabilities into their CUAS plans.

Kinetic Attack

Marines currently have limited means to physically attack enemy sUAS. Their small arms lack effective fire control systems for aerial objects, and rifleman cannot easily stabilize their weapons when shooting at high angles. Commanders must therefore consider the low likelihood of achieving destructive or even disruptive effects when issuing engagement criteria beyond individuals' self-defense. That doesn't mean we should *never* attempt with current weapons to shoot down enemy sUAS; far from it. It just means that commanders must consider the risk to unmasking their forces, causing fratricide to adjacent units, and more when weighing best responses to overhead sUAS. For defense against one-way attacks, the force being directly targeted, and not those around it, may have the best chance of defeating the inbound system simply because of a relatively constant bearing-to-target in the terminal stage. **Air sentry procedures should therefore include instructions on how to rapidly estimate and disseminate enemy sUAS direction and range to the friendly forces that are the likely target(s)**, rather than providing simple, general alerts.

Electronic Attack

This section concludes by presenting a powerful CUAS tool that is available right now. **Each MEF currently possesses hundreds of these man-portable systems that can be used to defeat enemy UAS by breaking their links to their operators—and there are enough of these weapons to provide one to every rifle squad in the Marine Corps**. They are the Modi II Dismounted EW Systems, a tool originally procured to defeat radio-controlled improvised explosive devices (RC-IEDs) in environments like Iraq and

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[15] Each Marine Air Wing currently maintains only *single-digit* inventories of the SkyView-MP UAS detection system as components of their Light Marine Air Defense Integrated Systems (LMADIS). The SkyView systems themselves could easily be de-coupled from the rest of the L-MADIS system-of-systems and employed by the GCE—they weigh less than six pounds and may be operated with standard radio batteries—but no plans for such a program currently exist.

Afghanistan. These systems are now largely held and maintained by Explosive Ordnance Disposal (EOD) elements at the Engineer Support Battalions (ESBs) and Combat Logistics Battalions (CLBs). Infantry units that obtain these systems from their MEFs can easily reprogram them for a counter-UAS (CUAS) role. Low Altitude Air Defense (LAAD) battalions maintain threat-based frequency loadsets that can be programmed into the Modis via Simple Key Loaders (SKL). Once loaded with the right frequencies, system operators have the ability to overpower enemy operators' links with their sUAS, denying their ability to control them or receive video feed. The range at which operators may be able to achieve these effects depends on the range from the UAS to its operator; the Modi jamming signal on the target frequency simply has to be stronger than the operator's, wherever the UAS is located.

To develop familiarity with CUAS EW systems and validate unit SOPs, forces must practice going "buzzer on" with them during home station training. For units just getting started, **these are the steps for getting clearance to operate lower-powered EW systems on a Marine Corps installation**:

1. Submit a (classified) frequency request to the base spectrum manager.

2. Coordinate with base range control for a training area that will minimally affect other units.

3. Notify base range control each time one of the systems switches between "buzzer on" and "buzzer off."

Some details and timelines may differ from one installation to another, but the above are generally the only hurdles that units need to clear. Bottom line: units that get their hands on Modis can start using them live for CUAS training and TTP development, right now.

Way Ahead

This document doesn't end with a conclusion, because for better or worse, serious sUAS efforts in the Marine Corps appear to be just getting started. But it does close with suggested priorities of work going forward—and an incomplete list at that. These are efforts at the tactical level, using gear we have now or will have soon, and not simply a wish list for future budgets. And these are efforts that Marines across the Corps (reader: that includes you) can start advancing, time now.

- Continue to develop, test, validate/refute, refine, and share best practices for sUAS deconfliction with air and surface fires and assets. For 1st and 2d Marine Divisions: consider concentrating available sUAS with battalions conducting the semi-annual TALONEXs in order to help drive refinements (and broader ACE acceptance and adoption) of sUAS and manned aircraft deconfliction measures.

- Recover and consolidate infantry battalion inventories of old InstantEye sUAS, fielded 2018-2019, for use today as adversary force training aids. Many of these older systems may be sitting, unused, in supply warehouses or company storage containers. These systems can be particularly useful for live CUAS training with LCMRs and Modi systems.

- Develop, test, validate and share a standard unit-level program of instruction to produce FOs and FDCs proficient in the sUAS Direct Alignment method.

- Develop a casing for M67 grenades that holds the spoon to the body during flight but shatters on impact with the ground. This would allow grenades to be dropped from higher than 400 feet. Spoon releases on impact would mean 4-5 seconds of reaction time for targeted enemy forces, but multiple grenades dropped at once could overwhelm any ability to escape or deflect. The principal advantage of this adaptation would be that operators could fly attack profiles from altitudes above audible range.

- Experiment with an M320-like, top-down attack launcher solution for stock 40mm munitions to be delivered by the SkyRaider. An appropriate attachment and safety controls for an M320 may be possible to 3D-manufacture. There would be tremendous benefit to a 40mm delivery system: a wide variety and large quantities of relatively effective munitions could now be delivered with pinpoint accuracy at ranges of multiple kilometers.

- Develop, test, and share a BB-2590 battery delivery system for the SkyRaider. Experimentation at Marine Corps Mountain Warfare Training Center demonstrated the value of this concept for infantry companies conducting sustained operations in limited-mobility environments. However, payload adapters are needed to better stabilize the batteries in flight and to prevent damage to them when dropped.

- Experiment with, establish, and share best practices for control of sUAS in the presence of enemy jamming.

- Draft a deliberate universal needs statement (D-UNS) for a sUAS/payload option that pulls accurate laser grids for targets selected in the optical viewfinder. This could remove the principal source of error (FO correlation of splash location on video with grid location on imagery) from the sUAS Direct Alignment method.