

靈巧的戰爭工具：跳脫技術導向理解小型無人機滲透*

Cunning Tools of War: Moving Beyond a Technology-Driven Understanding of sUAS Infiltration

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Preface

Small unmanned aircraft systems (sUAS) are shaping modern warfare. The capability of sUASs to bypass air defenses to provide targeting data, deliver munitions, and perform reconnaissance are their defining features in conflict across the world. Initially a convenient tool for situational awareness, sUASs now provide belligerents immense value through infiltration, which the U.S. Army's field manual on tactics (Field Manual 3-90, Tactics) defines as the "undetected movement through or into an area occupied by enemy forces."¹ Such infiltration by sUAS is an equalizer that has eroded the concept of air superiority by forcing all belligerents to defend against airborne threats even if one side of the conflict still controls the airspace above ten thousand feet. The area below this altitude, referred to as the air littoral, is now a contested space accessible to almost anyone.² Yet, sUASs do not fly with impunity—efforts to interdict or mitigate sUAS missions by the United States, Russia, Ukraine, and others have turned the air littoral into a back-and-forth struggle of adaptation to employ sUASs and their countermeasures.

前言

「小型無人機系統」(後續簡稱 sUAS)正在形塑現代戰爭，其能躲過防空系統偵測並提供標定數據、投放彈藥，以及執行偵察任務，這些特性使其在全球衝突中發揮作用。起初，sUAS 只是提升狀況覺知的便捷工具，如今已藉由滲透為交戰方提供巨大價值。美陸軍第 3-90 號野戰手冊《戰術》將滲透定義為「在不被偵測情況下，穿越或進入對方佔領區。」¹ sUAS 的滲透成為一種平衡力量，削弱空中優勢的概念，這意思是說即使某方已掌控一萬英呎以上空域，每個交戰方還是必須防備這個高度以下的空中無人機威脅。一萬英呎以下的空中近岸區，如今成為幾乎任何人都可以競

* 本文屬於公開出版品，無版權限制。

¹ Field Manual (FM) 3-90, *Tactics* (Washington, DC: U.S. Government Publishing Office [GPO], 2023), 2-24.

逐的空間。²然而，sUAS 並非都能毫無阻礙地飛行，因為美國、俄羅斯、烏克蘭及其他國家都為了能攔截或削弱無人機做出許多努力，空中近岸區成為無人機攻防的兵家必爭之地。

The United States is investing in both sides of this struggle, and military leaders such as Lt. Gen. Sean Gainey, commander of U.S. Army Space and Missile Defense Command, have emphasized the need to generate advanced technical capabilities to maintain an edge in the battle between sUAS infiltration and counter-UAS (C-UAS).³ Yet history shows us that success in warfare requires more than a technical edge, and C-UAS is more than a material problem. Success in the air littoral also requires an effective doctrine of employment. This idea echoes in the U.S. Department of Defense's strategy document for C-sUASs.⁴ More fundamentally, success on both sides of this struggle requires a deep understanding of the causal logic of successful sUAS infiltration at the tactical level.

美軍不斷地投資無人機攻防，軍事將領如美陸軍太空暨飛彈防衛司令部司令肖恩·蓋尼中將強調，美軍需要發展先進的技術能力，才能在 sUAS 滲透與反制無人機（C-UAS 後續簡稱反制無人機）之間的攻防中保持優勢。³然而，歷史告訴我們，戰爭成功不僅取決於技術優勢，也就是無人機反制不光是裝備武器的問題，要在空中近岸區取得成果，還需要一套有效的運作教則，這種觀點與美國防部的反制小型無人機戰略文件相互呼應。⁴根本而言，無人機攻防戰孰者勝出？取決誰能有效掌握 sUAS 在戰術層級的滲透運作邏輯。

Although technical mismatches play an important role in most sUAS infiltrations, close inspection of sUAS use in Ukraine, the Middle East, and the southern border of the United States reveals that these aircraft exploit other tactical means. Put simply, successful sUAS infiltration is far more than a technological battle—it is a tactical art. Moreover, if properly employed, this tactical art provides opportunities to produce effects in areas otherwise inaccessible or even denied to military operations. Likewise, C-sUAS efforts must acknowledge and respond to this tactical

² Maximilian K. Bremer and Kelly A. Grieco, "The Air Littoral: Another Look," *Parameters* 51, no. 4 (17 November 2021): 68, <https://doi.org/10.55540/0031-1723.3092>.

³ *Center for Strategic and International Studies: Countering Uncrewed Aerial Systems: A Conversation with General Sean Gainey*, YouTube video, posted by "Center for Strategic & International Studies, 14 November 2023, <https://www.youtube.com/watch?v=szkb2MrhWzE>. Sarah Fortinsky, "Top Ukrainian Military Officer Says War with Russia at a 'Stalemate,'" *The Hill*, 2 November 2023, <https://thehill.com/policy/international/4290701-ukrainian-general-war-russia-stalemate/>.

⁴ U.S. Department of Defense (DOD), *Counter-Small Unmanned Aircraft Systems Strategy* (Washington, DC: DOD, January 2021), 14.

art.

雖然大多數 sUAS 滲透是採取以小搏大的技術不對稱方式，但仔細檢視它們在烏克蘭戰場、中東地區及美國南部邊境的使用情形，就可以發現這些飛行器還是運用戰術手段。簡言之，成功的 sUAS 滲透不僅是一場技術戰，它更是一門戰術藝術。由此可見，若吾人運用得當，就能在阻絕區或軍事行動無法抵達的區域產生影響力。同理可證，要反制無人機也必須先理解再應對這種戰術藝術。

Technology, Tactics, and Causal Logic

History indicates that technology requires an effective concept of employment to deliver success in battle. One particularly fitting example is the use of radar during World War II. Although both Germany and the Allies developed technically advanced radar systems, the British understood the new logic of technological change for air defense.⁵ The speed of modern aircraft meant that defenders needed an early and accurate report of incoming air raids to enable effective preparation. This required linking radar systems together and fusing this information with other intelligence. To execute this concept, the British centralized all detection systems into a single station that could build a common intelligence picture and relay it to the fighter command during the Battle of Britain. Simply put, the British understood that the tactical logic of air defense was combining sensors to enable advanced warning. In contrast, the Germans used their radar systems as extensions of preexisting human observer corps that remained relatively independent of each other. Ultimately, the German approach proved less effective despite leveraging highly advanced radar systems.⁶

技術、戰術和運作邏輯

歷史顯示技術需要配合有效的戰術運用概念，才能在戰場上克敵制勝。特別適合列舉的案例是二戰期間雷達的使用，雖然德國與同盟國都開發了技術先進的雷達系統，但英國理解防空方面上技術變革的新邏輯。⁵以現代飛機速度而言，防守方必須及早且準確獲取空襲情報，才有辦法做好充足準備，這需要鏈結所有雷達系統，並將雷達系統的資訊與其他情報相互整合。為了貫徹這個概念，英國在不列顛之戰期間將所有偵測系統集中至單一站點，以建構共同情報圖像並將之傳送給戰鬥指揮部。總歸來說，英國因為理解防空的戰術邏輯在統合不同的感測器，才能達到提前預警作用。相較之下，德國卻只將雷達系統視為人工觀察團的延伸，況且這些部隊彼此間並未互

⁵ Alan Beyerchen, "From Radio to Radar: Interwar Military Adaptation to Technological Change in Germany, United Kingdom, and the United States," in *Military Innovation in the Interwar Period*, ed. Williamson R. Murray and Allan R. Millett (New York: Cambridge University Press, 1996), 286–87.

通有無。結果，雖然德軍握有技術先進的雷達系統，但作戰效能不彰。⁶

Table. Tactical Logic of sUAS Infiltrations

Tactical Logic 1 (Physical): <i>Operate beyond the responsive capabilities of the adversary (physical and/or technical)</i>	Tactical Logic 2 (Cognitive): <i>Use uncertainty and dilemmas to impede an adversary's effective response</i>
Tactic 1.1: Use technical advantages to create gaps in the adversary's C-UAS cycle. Tactic 1.2: Use <i>intelligence</i> to find gaps in the adversary's C-UAS cycle. Tactic 1.3: Instead of precise intelligence, employ large numbers of expendable sUAS to locate gaps in the adversary's defenses.	Tactic 2.1: Make it difficult for the adversary to separate friend from foe. This includes manipulation of the adversary's rules of engagement. Tactic 2.2: Compress time available for the adversary to analyze the threat and respond. Tactic 2.3: Use mass to divide the adversary's resources and force decisions on which sUAS to interdict.

循環中的漏洞

戰術邏輯 1.3：若缺少精確情報，可運用大量消耗型 sUAS 找出敵方防禦中的漏洞

時間

戰術邏輯 2.3：運用數量優勢來分散敵方資源，迫使其做出該攔截哪架 sUAS 的決定

(Table by author)

(製表：本文作者)

So what is the tactical logic of sUAS infiltrations? This article presents evidence of two distinct but complementary logics that are summarized in the table. The first and most obvious logic is operating beyond the responsive capabilities of the adversary (Tactical Logic 1). The concept of infiltration does not rely on forcible entry. Instead, sUAS infiltration must frustrate or avoid altogether an opponent's ability to execute countermeasures. Avoiding detection is not a requirement per se, but the logic requires the infiltrating force to avoid detection and engagement or at least reduce exposure.⁷ sUAS infiltration may succeed by taking advantage of gaps in any part of the C-UAS cycle that includes several steps: (1) detecting an airborne object, (2) identifying its relevant characteristics, (3) classifying it as a threat, (4) prioritizing a response, (5) deciding on an engagement method, (6) engaging the sUAS, and (7) exploiting information from the event to improve further efforts.⁸

那麼，sUAS 滲透的戰術邏輯為何？本文提出兩種截然不同卻又相輔相成的戰術邏輯，彙整成表。第一種也是最顯著的邏輯，做出超出敵方反應能力之外的行動（戰術邏輯 1）。滲透的概念並不是強攻，正確來說是要挫敗或是讓對手失去執行反制措施的能力，避免被偵測本身並非必要條件，但基本要求是滲透部隊應盡可能避免被偵測或與敵交戰，或者是減少暴露程度。⁷ sUAS 滲透可以利用反制無人機循環中的任何一個環節漏洞，該循環包含以下幾個步驟：一、偵測空中目標；二、識別相關特徵；三、歸類為威脅；四、因應的優先順序；五、決定交戰方式；六、對 sUAS 進行交戰；

⁶ Ibid., 274.
⁷ FM 3-90, *Tactics*, 2-24.

七、利用該事件的資訊來精進後續作為。⁸

Technical advantages provide just one option to operate outside of the capabilities inherent to this cycle (Tactic 1.1). Another way is to find gaps in C-sUAS system coverage that result from any variety of battlefield choices by the adversary. A technical advantage may permit an aircraft to fly through the expected coverage of a C-sUAS system undetected, but the latter approach might locate an area of dead space to fly around the coverage. Locating and exploiting these gaps is essentially a function of intelligence (Tactic 1.2). Additionally, sUAS infiltration can simply use mass in the form of large numbers of sUASs to find these vulnerabilities by attrition rather than precise intelligence (Tactic 1.3). Each case study of sUAS infiltration will show that although a technical edge provides one means to satisfy the first logic of sUAS infiltration, the other methods are very much in play.

技術優勢僅是突破反制無人機循環的一種手段（戰術邏輯 1.1），另一種手段是尋找無人機反制範圍的漏洞，因為敵人面對詭譎多變的戰場難免疏漏。擁有技術優勢，無人機就能不被偵測地飛越反制無人機的覆蓋範圍，甚至還能從中找到滲透的死角。定位並利用這些漏洞在本質上是一項情報運用功能（戰術邏輯 1.2）。此外，sUAS 滲透還可以利用大規模消耗戰而不是運用準確情報來發現漏洞（戰術邏輯 1.3）。雖然每個 sUAS 滲透的研究案例都指向，技術優勢是符合滲透邏輯的手段，但其他手段同樣也能發揮作用。

The second logic of sUAS infiltration is using uncertainty and dilemmas to impede an effective response by the adversary (Tactical Logic 2). Whereas the first is essentially physical, this second logic occurs primarily in the cognitive domain. This is a far more subtle approach that relies on the fact that detection and identification technology rarely provide certainty, and effective use of the airspace by the adversary often requires C-sUAS concessions and trade-offs with other tactical interests. By leveraging these cognitive seams, sUAS infiltrations effectively burden the human decision-maker in war. Although this approach may not be deliberate in every case, it often plays a key role in success.

滲透邏輯的第二種方法，運用不確定性與兩難困境，阻礙敵方做出有效回應（戰術邏輯 2）。相較於第一種滲透邏輯，第二種主要發生在認知領域，承認偵測與識別技術準確性不高這個事實，以及敵人在空域利用最大化時往往必須在反制無人機做

⁸ Army Techniques Publication (ATP) 3-01.81, *Counter-Unmanned Aircraft System (C-UAS)* (Washington, DC: U.S. GPO, 2023), 3-9-3-17.

出讓步，以換取某些戰術利益。權衡利弊認知領域的弱點，確實造成 sUAS 戰場決策人員額外負擔。雖然這種方法不一定在每個狀況下可以面面俱到，但往往能成為達成任務的關鍵。

Subsequent examples from across the world show three general techniques for exploiting this tactical logic. The first method uses the tactical situation to make it difficult for the adversary to separate friend from foe (Tactic 2.1). sUAS infiltrations may accomplish this by either making their identity ambiguous or by flying in ways that make it difficult for the adversary to engage without damaging its own aircraft or resources. The second method is simply to compress reaction time. This creates cognitive stress during decision-making and physically limits the responses available (Tactic 2.2). The final method is using mass employment to force difficult decisions on how to prioritize assets (Tactic 2.3). Mass plays an important role in both the physical and cognitive logic of sUAS infiltration.

綜觀世界各地的以下各種案例研究顯示，認知領域的戰術邏輯運用可以區分以下三種手段：第一種是利用戰術情境，讓對方難以區分敵我（戰術邏輯 2.1），也就是 sUAS 滲透時可以隱匿身分讓人無法分辨，或是讓對手為難於接戰將發生損害自身飛機或資源的情況。第二種是單純壓縮對方反應時間，也就是在決策過程中造成對方認知上壓力，並在實體上限制可用的應對作法（戰術邏輯 2.2）。第三種是藉由大規模部署來迫使決策者在資源優先順序上做出困難抉擇（戰術邏輯 2.3）。不管是在實體面或是認知面的 sUAS 滲透，大規模部署都扮演重要角色。

Short-Range sUAS Infiltration in Ukraine

The battles fought in Ukraine are undoubtably the most developed examples of sUAS infiltration to date. Since the invasion in 2022, sUASs have provided a critical means of locating and destroying critical targets beyond the forward line of troops. Even when these operations are conducted across just a kilometer or two, they still provide a critical sensor or munition in relatively inaccessible locations. The intensity of this kinetic conflict has prompted innovation on both sides, resulting in a diverse set of tactics and techniques to execute sUAS infiltration and prevent them.

烏克蘭的短程 sUAS 滲透

烏克蘭無疑是迄今為止 sUAS 滲透案例最多的地方，自 2022 俄軍入侵以來，sUAS 已成為鎖定並摧毀敵後方輜重區的關鍵手段。雖然 sUAS 作戰範圍僅在一兩公里內，但卻能對難以接近地區進行重要偵察與投放彈藥。這種動態衝突的激烈程度驅使烏俄雙方不斷創新，從而發展出各種戰術戰法來執行各種 sUAS 的滲透與反制作

為。

The primary tension at the tactical level is the use of electronic warfare, especially jamming, global navigation satellite system (GNSS) spoofing, and cyber-enabled techniques.⁹ Whereas kinetic C-sUAS methods require precise targeting data that can be difficult to obtain against small aircraft that are inherently difficult to detect, these methods exploit the radio frequency connection required by sUASs to control the aircraft, receive GNSS data, and provide a video feed. These techniques are also cost-effective and do not require munitions that may be exceedingly expensive.¹⁰

戰術層面主要對抗是運用電子戰，尤其是干擾訊號、混淆全球衛星定位系統（GNSS），以及運用網路輔助技術等。⁹反制無人機需要精準的標定數據，但是小型飛行器本身就難以偵測，至於這些反制方法則利用有干擾 sUAS 飛行時與無線電頻率的連接、擾亂全球衛星定位系統訊號（GNSS）接收，以及阻礙影像傳輸。這種技術面反制無人機方法既不用耗費昂貴彈藥又具成本效益。¹⁰

Technical advantages have played an important role in enabling Ukrainian sUASs to succeed in the face of substantial electronic warfare capabilities on both sides, especially jamming (Tactic 1.1).¹¹ Although recent Russian improvements in jamming have resulted in as many as ten thousand sUAS losses per month for Ukraine, technical advancements have allowed a small number of Ukrainian sUASs to succeed. According to open-source reporting, these advances may be improvements in shielding methods, an automatic ability to detect and use unjammed frequencies, better filters that block out noise, or something else.¹² Another less sophisticated technical approach has been using the momentum of small first-person view drones to carry munitions to their target even after successful jamming and the loss of control by the operator. This works because Russian jammers such as the RP-377 reportedly only work at a short range (less than one hundred feet).¹³ With the advent of more capable jammers such as the Volnerez and Saniya, the range of this type of jamming is increased, which will require more sophisticated sUAS navigation systems to maintain a favorable technical mismatch.¹⁴ This

⁹ Paul Mozur and Aaron Krolik, "The Invisible War in Ukraine Being Fought Over Radio Waves," *New York Times* (website), 19 November 2023, <https://www.nytimes.com/2023/11/19/technology/russia-ukraine-electronic-warfare-drone-signals.html>; Sam Skove, "How Ukraine Learned to Cloak Its Drones from Russian Surveillance," C4ISRNet, 17 October 2022, <https://www.c4isrnet.com/battlefield-tech/2022/10/17/how-ukraine-learned-to-cloak-its-drones-from-russian-surveillance/>.

¹⁰ Jon Harper, "Army Buys 600 Additional Coyote Counter-Drone Weapons amid Attacks on US Troops," *DefenseScoop*, 9 February 2024, <https://defensescoop.com/2024/02/09/army-600-coyote-counter-drone-rtx/>.

fleeing advantage is an example of the inherent weakness of relying on technical advantages alone.

科技優勢讓烏克蘭 sUAS 電子戰交戰發揮重大作用，尤其是干擾(戰術邏輯 1.1)。¹¹雖然俄軍近期在干擾技術有所提升，導致烏軍每月損失多達一萬架 sUAS，但烏軍憑藉技術優勢，讓一小批 sUAS 仍能成功突圍並執行任務。根據公開報導指出，烏軍精進屏蔽技術、自動偵測，以及使用未被干擾頻率、效能更好的噪音過濾器或是其他裝置。¹²另一種較不複雜的技術是利用第一人稱視角小型無人機具備的慣性動能特性，也就是其在被干擾且脫離操作手的控制後，仍可以藉由剩餘動能將彈藥投擲至目標區。這方式奏效，因為俄軍 RP-377 干擾器的有效干擾距離，只能在不到 100 英尺的短距離，¹³但隨著像 Volnerez 和 Saniya 這類更先進的干擾器出現，干擾範圍將有所擴大，這意味著需要更先進的 sUAS 導航系統，才能維持技術上的不對稱優勢。¹⁴上述這種稍縱即逝的優勢凸顯單靠技術優勢的先天弱點。

Instead of relying on an outright technical mismatch, Ukrainians use intelligence to locate gaps in jammer coverage and frequencies that Russians are not actively jamming (Tactic 1.2). These gaps result from several factors. One source of the gaps is the fact that Russians have been keeping their more valuable jammers far from the front lines.¹⁵ This is likely due to their targetable electromagnetic signature. Another source of gaps may be the requirement for Russians to reduce electromagnetic fratricide with their communications, an issue that many analysts believe explains the impotency of Russian electronic warfare during the initial invasion.¹⁶ U.S. Army doctrine acknowledges that these factors are inherent characteristics of electronic warfare, which means that gaps of some kind will be present for those cunning enough to use them.¹⁷ Other gaps may be due to the movement of equipment during major troop movements or simply mistakes. Whatever the reason, successful Ukrainian sUAS infiltrations appear to leverage

¹¹ Jack Watling and Nick Reynolds, *Meatgrinder: Russian Tactics in the Second Year of Its Invasion of Ukraine* (London: Royal United Services Institute, 19 May 2023), iii, <https://www.rusi.org/explore-our-research/publications/special-resources/meatgrinder-russian-tactics-second-year-its-invasion-ukraine>.

¹² David Hambling, "How Have Ukrainian Drones Beaten Russian Jammers: And Will It Last?," *Forbes* (website), 9 August 2023, <https://www.forbes.com/sites/davidhambling/2023/08/09/how-did-ukraine-beat-russias-drone-jammers/>; David Hambling, "Jam Buster: How Ukraine's 'Secret Weapon' Shrugs Off Russian Radio Interference," *Popular Mechanics* (website), 16 February 2023, <https://www.popularmechanics.com/military/a42922481/tricopter-drone-atlaspro-resists-russian-jamming/>.

¹³ David Axe, "More and More Russian Vehicles Have Drone-Jammers. Ukrainian Drones Blow Them Up Anyway," *Forbes* (website), 22 December 2023, <https://www.forbes.com/sites/davidaxe/2023/12/22/more-and-more-russian-vehicles-have-drone-jammers-ukrainian-drones-blow-them-up-anyway/>.

¹⁴ David Axe, "As the Ukrainians Fling 50,000 Drones a Month, the Russians Can't Get Their Drone-Jammers to Work," *Forbes* (website), 16 February 2024, <https://www.forbes.com/sites/davidaxe/2024/02/16/as-the-ukrainians-fling-50000-drones-a-month-at-the-russians-the-russians-cant-get-their-drone-jammers-to-work/>.

these opportunities through the use of intelligence, including maps of electromagnetic activity.¹⁵

烏軍並非單靠技術上優勢，還藉由情報運用來發現干擾覆蓋範圍的漏洞，以找出俄軍未積極干擾的頻率（戰術邏輯 1.2）。形成這些漏洞有多種原因，其中原因之一是俄軍為避免較貴重干擾器的電磁信跡遭敵鎖定，將之部署在遠離前線位置。¹⁶另一個原因可能是俄軍為避免與自身通信系統之間的電磁誤傷，許多分析師認為這正是俄軍在入侵初期電子戰表現乏力的主因。¹⁷從美陸軍準則的觀點來看，這些因素是電子戰的固有特性，這意味著只要一方夠機靈總會存在可資利用的空隙，¹⁸另可能的原因是設備跟著部隊大規模調動一併移轉時，不小心留下蛛絲馬跡。無論原因為何，烏克蘭 sUAS 的成功滲透，相信是透過如電磁活動地圖等情報運用來抓住這些機會。¹⁹

Another central component of Ukraine's UAS strategy is to use mass to locate these gaps instead of precise intelligence (Tactic 1.3). This is possible because of two inherent qualities of sUAS. First, sUASs are unmanned. Although the controllers are always vulnerable to targeting, sUAS missions do not carry the same physical risk as manned infiltrations. Second, by keeping the manufacturing requirements low for sUASs, Ukrainians can afford attritive tactics in which only small numbers of aircraft survive infiltration. Some Ukrainian sUAS units report successful attacks for just 10 percent of their missions.²⁰ Yet, large numbers of sUASs can try different routes and different frequencies until weak points are discovered and exploited. This is a significant argument that some Ukrainian commanders have made against shifting to more expensive, technically advanced sUAS models.²¹

烏克蘭無人機戰略的另一個核心要素，為利用數量優勢來發現這些空隙，這時候就不用靠精確的情報（戰術邏輯 1.3）。之所以可行，原因在於 sUAS 有兩個先天特性：第一，sUAS 是以無人方式飛行，雖然操作手的仍可能成為攻擊目標，但在執行任務時不會像有人飛行滲透那樣危險；第二，由於 sUAS 的製造要求水準較低，消耗性戰術成本是烏克蘭可以承擔的範圍，即便最終只會有少量無人機滲透成功。一些烏軍的 sUAS 單位回報，大約只有一成的無人機攻擊任務成功率。²²儘管如此，藉由大

¹⁵ "The New Battle of the Beams," in *Economist* (website), special report, 3 July 2023, 6, <https://www.economist.com/special-report/2023/07/03/the-latest-in-the-battle-of-jamming-with-electronic-beams>.

¹⁶ Justin Bronk, Nick Reynolds, and Jack Watling, *The Russian Air War and Ukrainian Requirements for Air Defence* (London: Royal United Services Institute, 7 November 2022), 13, <https://rusi.org/explore-our-research/publications/special-resources/russian-air-war-and-ukrainian-requirements-air-defence>.

¹⁷ FM 3-12, *Cyberspace Operations and Electromagnetic Warfare* (Washington, DC: U.S. GPO, 2021), 2-9.

¹⁸ *Economist*, "The New Battle of the Beams," 6.

¹⁹ Joshi Shashank, "How Cheap Drones Are Transforming Warfare in Ukraine," *Economist* (website), 5 February 2024, <https://www.economist.com/interactive/science-and-technology/2024/02/05/cheap-racing-drones-offer-precision-warfare-at-scale>.

量無人機同時嘗試不同路徑與頻率，還是能發現敵方弱點並加以利用，據此烏軍指揮官反對往成本更高、技術更先進 sUAS 型號發展。²⁰

In addition to creating or finding gaps in electronic warfare defense, Ukrainian infiltrations impose dilemmas on Russian commanders (Tactic 2.1). Electromagnetic fratricide offers an obvious opportunity to do so. According to the commander of Ukraine's Aerorozvidka unit in 2022, one tactic involves executing sUAS missions when Russians are launching and employing their own sUASs to make it more difficult for the Russian commander to employ his own jamming capabilities.²¹ The ability of Russians to coordinate electronic warfare with their own operations has improved since, but the same concept should still apply, albeit using more refined methods. If successful at flying at the same times, places, and frequencies as the adversary's aircraft, infiltrating sUASs put the Russian commander in a difficult position—begin jamming and lose his aircraft or attempt less effective protective measures and risk conceding a successful Ukrainian sUAS infiltration. This type of dilemma plays to the advantage of the infiltrating sUASs.

除了製造或發現電子戰防禦的空隙外，烏克蘭無人機滲透行動也構成俄軍指揮官的難題（戰術邏輯 2.1），電磁誤傷是一個造成這種困境的切入點。根據烏軍空中偵察部隊指揮官在 2022 年的說法，這種戰術作為是在俄軍發射並使用其 sUAS 的同時，同步執行烏軍 sUAS 的行動任務，藉此讓俄軍指揮官難以啟動其干擾系統。²¹雖然俄軍知悉弱點後已提升電子戰與作戰行動的協調能力，但同樣的戰術概念仍然適用，只是需要以更精細的手法來執行。烏軍若能成功與俄軍無人機在相同時間、地點和頻率下飛行，sUAS 的滲透就會讓俄軍指揮官陷入兩難：啟動干擾，可能會讓己方無人機失效；不干擾，就只能採取效果較差的防護措施，冒著讓烏軍無人機成功滲透的風險。這種兩難困境對烏軍來說是一個有利條件。

One-Way Unmanned Aerial Vehicles in the Middle East

Since the Islamic State first began using the tactic in 2016, U.S. forces, allies, and their partners in the Middle East have been grappling with sUAS infiltration.²² The latest perpetrators have been Iranian-backed militias who employ “one-way UAV” (unmanned aerial vehicle) attacks in which explosive-laden sUASs fly into targets on American bases across the region. Between October and November

²⁰ Andrew E. Kramer, “Budget Drones Prove Their Value in a Billion-Dollar War,” *New York Times* (website), 22 September 2023, <https://www.nytimes.com/2023/09/22/world/europe/ukraine-budget-drones-russia.html>.

²¹ Julian Borger, “The Drone Operators Who Halted Russian Convoy Headed for Kyiv,” *Guardian* (website), 28 March 2022, <https://www.theguardian.com/world/2022/mar/28/the-drone-operators-who-halted-the-russian-armoured-vehicles-heading-for-kyiv>.

2023, American bases received over fifty attacks involving either sUASs or rockets.²³ Although most of these attacks have failed to inflict significant damage, a select number of sUAS infiltrations have inflicted serious casualties. An attack on 23 March 2023 killed a U.S. contractor, and another attack on 24 January 2024 killed three U.S. soldiers at the Tower 22 outpost in Jordan.²⁴ Other attacks have been close calls—attacks between October and November 2023 failed to cause significant damage but resulted in at least fifty-six injuries.²⁵ Given the grave consequences of sUAS infiltration into American bases, the Middle East is a critical case study to investigate.

中東地區的單程無人機

自伊斯蘭國在 2016 年開始使用單程無人機（自殺攻擊）戰術以來，美軍與盟軍及在中東夥伴國一直在應對 sUAS 的滲透問題。²²最近一次麻煩製造者是伊朗支持的民兵組織使用單程無人機發動攻擊，這些裝載炸藥的 sUAS 直接飛往該區域的美軍基地。在 2023 年 10 月至 11 月間，美軍基地遭受超過 50 起關於 sUAS 或火箭彈的攻擊，²³雖然大多數攻擊並未造成重大損壞，但少數幾次 sUAS 的滲透行動卻導致嚴重死傷。在 2023 年 3 月 23 日的攻擊事件中，造成一名美國承包商死亡，另在 2024 年 1 月 24 日的事件中，位於約旦的「塔樓 22 號」前哨站遭受無人機攻擊，造成三名美軍士兵死亡。²⁴其他的攻擊事件則是與死神擦肩而過，也就是發生在 2023 年 10 月至 11 月間的事件，雖然未造成重大破壞，但仍導致至少 56 人負傷。²⁵鑑於 sUAS 滲透美軍基地造成的嚴重後果，中東地區成為一個關鍵的案例研究對象。

Like Ukraine, successful one-way UAS attacks in the Middle East find ways to operate beyond our capability to detect and ultimately respond to these aerial threats (Tactical Logic 1). In some cases, this success likely benefits from technical mismatches between sUAS and the C-UAS used to defend U.S. bases in Iraq, Syria, and Jordan (Tactic 1.1). Class III UASs like the Iranian-made Shahed-136 are relatively small, can fly exceedingly low, and are made of lightweight material that

²² Don Rassler, *The Islamic State and Drones: Supply, Scale, and Future Threats* (West Point, NY: Combating Terrorism Center at West Point, July 2018), 1, <https://etc.westpoint.edu/wp-content/uploads/2018/07/Islamic-State-and-Drones-Release-Version.pdf>.

²³ Sabrina Singh, “Defense Department Briefing,” C-SPAN video, 28:28, 14 November 2023, <https://www.c-span.org/video/?531875-1/defense-department-briefing>.

²⁴ Jim Garamone, “U.S. Responds to Attack That Killed U.S. Contractor in Syria,” DOD video, 18:36, 24 March 2023, <https://www.defense.gov/News/News-Stories/Article/Article/3341127/us-responds-to-attack-that-killed-us-contractor-in-syria/>; C. Todd Lopez, “3 U.S. Service Members Killed, Others Injured in Jordan Following Drone Attack,” DOD video, 29:54, 29 January 2024, <https://www.defense.gov/News/News-Stories/Article/Article/3659809/3-us-service-members-killed-others-injured-in-jordan-following-drone-attack/>.

²⁵ Meghann Myers, “Number of Troops Injured in Drone Attacks Jumps to 56,” *Military Times* (website), 9 November 2023, <https://www.militarytimes.com/news/your-military/2023/11/09/number-of-troops-injured-in-drone-attacks-jumps-to-56/>.

further lowers its radar cross-section.²⁶ In some cases, these advantageous technical characteristics may be enough to avoid detection without any other tactical sophistication. Early attacks in 2021 appeared to avoid many of the technical detection and engagement options available.²⁷ However, the fact that many recent attacks are intercepted or otherwise unsuccessful suggests additional causal factors for the select cases that do strike their targets.

如同烏克蘭的情況一樣，中東地區單程無人機的成功攻擊事件，說明其行動能力已超越美方偵測與終端因應空中威脅能力（戰術邏輯 1）。部分成功案例顯示，sUAS 與美軍部署於伊拉克、敘利亞及約旦基地的反制無人機系統，兩者之間存在技術跟不上的問題，進而造成防禦罅隙（戰術邏輯 1.1）。第三類無人機如伊朗製的「見證者-136」，由於其體積相對較小、具超低空飛行能力、採用輕材質構造，可以大幅降低雷達截面積，增加突防機率。²⁶在某些情況下，只要具備這些技術上優勢，就可以躲避偵測，無須其他複雜的戰術手段，如同 2021 年初期的突防事件顯示，該型無人機成功規避許多技術偵測與反制。²⁷不過，近期發生多數攻擊遭到攔截或未能達成預期效果的事件，凸顯少數成功案例可能另有其他原因促成。

Although not employed in the same numbers as observed in Ukraine, sUAS attacks on U.S. bases are frequent and provide multiple opportunities for Iranian-backed militias to breach air defenses (Tactic 1.3). Retired Gen. Kenneth McKenzie Jr., former commander of the U.S. Central Command, has articulated this logic differently: “If the opponent is allowed to continue these [sUAS] attacks on such a scope and scale, eventually they’re going to get lucky with something.”²⁸ However, because sUASs are inherently cheap, mass employment provides success not through luck but through statistical probability. If there is any gap in coverage for any reason, including maintenance needs, operator error, dead space, or some abnormal phenomena, high numbers of low-risk missions provide a tactical means of capitalizing on the smallest of vulnerabilities. This does not imply that this approach is haphazard either—there is a long insurgent tradition in the Middle East of probing U.S. positions systematically to find vulnerabilities.²⁹ Therefore, unless future technical prowess reduces these tactical seams to zero, mass employment of sUASs will retain a meaningful tactical logic.³⁰

²⁶ Uzi Rubin, “Russia’s Iranian-Made UAVs: A Technical Profile,” Royal United Services Institute, 13 January 2023, <https://www.rusi.org/explore-our-research/publications/commentary/russias-iranian-made-uavs-technical-profile>.

²⁷ Louisa Loveluck and John Hudson, “Iran-Backed Militias Turn to Drone Attacks, Alarming U.S. Forces in Iraq,” *Washington Post* (website), 29 May 2021, https://www.washingtonpost.com/world/middle_east/iraq-militia-drones-threat/2021/05/28/864e44d0-bc8f-11eb-922a-c40c9774bc48_story.html.

中東地區無人機使用規模雖不如烏克蘭戰場那般密集，但伊朗支持的民兵組織仍持續使用 sUAS 攻擊美軍基地，藉機多次穿透防空網。美國中央司令部前司令肯尼斯·麥肯錫備役上將對這種邏輯的解釋是：「若敵方持續在這種規模與頻率下使用 sUAS 進行攻擊，他們最終可能會在某次行動中意外取得成功。」²⁸然而，由於 sUAS 成本平價，大量部署產生的成功結果並非是靠運氣，而是基於統計機率論的原理。若防空系統因某種因素，如維保作業、操作失誤、空域死角或其他異常現象而導致防禦覆蓋出現空隙，這時候大量出動且低風險的行動就可以成為一種戰術手段，針對這些微小的脆弱點加以利用。事實上，中東叛亂分子向來都會以系統性方式找出美軍陣地防守的弱點，這種集體出動方式並非是亂槍打鳥。²⁹由此可見，除非未來科技能完全填補戰術漏洞，否則大量使用 sUAS 仍將是一項實用的戰術邏輯。³⁰

There is also potential for Iranian-backed militias to employ the cognitive logic of sUAS infiltrations in the Middle East (Tactical Logic 2) by mimicking other military or civilian aircraft to delay or prevent engagement by coalition forces (Tactic 2.1). Several factors make this an exploitable possibility against U.S. forces. First, the U.S. Army techniques publication (ATP) for C-UASs (ATP 3-0.1.81, Counter-Unmanned Aircraft System) notes, “the proliferation of friendly joint and multinational UASs, many of which do not have identify-friend-from-foe (IFF) capability.”³¹ This opens the door for technical difficulties to distinguish between friendly and adversarial aircraft. Second, although newer systems such as the Low, Slow, and Small UAV Integrated Defeat System (LIDS) can synchronize several detection and engagement options into one system, the large family of C-UASs employed by the Department of Defense still require some level of human coordination to reconcile information on aircraft detections.³² These factors are featured in a report by the Center for Strategic and International Studies, concluding that “over the near term, identification will depend more on context or procedures than specific Identification Friend or Foe (IFF) systems.”³³ These coordination mechanisms provide valuable tactical opportunities that a cunning adversary can exploit for their benefit. Finally, as with electronic warfare in Ukraine, even when

²⁸ Alex Horton et al., “U.S. Troops Killed, Wounded in Jordan Attack Blamed on Iranian Proxies,” *Washington Post* (website), 28 January 2024, <https://www.washingtonpost.com/politics/2024/01/28/americans-killed-drone-jordan/>.

²⁹ Jerry Meyerle and Carter Malkasian, *Insurgent Tactics in Southern Afghanistan, 2005–2008* (Alexandria, VA: Center for Naval Analysis Strategic Studies Division, August 2009), 6–8.

³⁰ Similarly, although there is little readily available information on the use of specific intelligence to find these sUAS vulnerabilities (Tactic 1.2), insurgents have repeatedly shown the capability to collect on operations inside bases across the Middle East. 同樣地，雖然關於使用特定情報來找出 sUAS 弱點的資訊不多（戰術邏輯 1.2），但叛亂分子已多次展現有能力對中東地區的美軍基地進行情蒐。

U.S. forces can identify aircraft accurately, they may be unable to engage inbound sUASs due to fratricide concerns, especially if there are manned friendly aircraft in vicinity of the infiltrating adversary's sUASs.

在中東地區，伊朗支持的民兵組織也有可能利用 sUAS 在滲透行動中的認知邏輯（戰術邏輯 2），也就是藉由偽裝成其他的軍用或民用飛行器，以遲滯甚至阻止聯軍進行交戰（戰術邏輯 2.1）。敵方這個戰術選項之所以可行，是因為美軍存在若干因素所致。首先，根據美陸軍技術出版品第 3-0.1.81 號《反制無人機系統》指出，友軍與多國部隊使用無人機頻率日益增加，但不少無人機仍缺乏敵我識別能力，³¹這導致在分辨敵我飛行器時出現技術問題。其次，像「低空、慢速、小型無人機整合打擊（LIDS）」這類新式系統，雖然能將偵測與打擊整合為一體，但美國防部使用反制無人機系統仍需要某種程度的人為協調，以判讀飛行器的偵測資訊。³²戰略暨國際研究中心（CSIS）的一份報告也指出這些因素，「鑑於無人機數量迅速增加，在短期內，敵我識別將更為依賴情境或程序的判斷，而非靠敵我識別系統功能。」³³人為協調機制產生的漏洞，可能成為機靈對手寶貴戰術機會。最後，如同在烏克蘭的電子戰情況一樣，即使美軍可以準確識別飛行器，也可能會為了不誤傷友軍而對來襲的 sUAS 進行打擊時有所顧忌，尤其是友軍有人駕駛飛機鄰近敵方 sUAS 的時候。

Exacerbating this situation is that U.S. forces have very little time to make engagement decisions, a fact that is exploitable by adversaries in the Middle East (Tactic 2.2). Discussions with those involved in C-UAS operations in the region indicate that one of the most challenging factors is that engagement decisions must be made in a matter of minutes.³⁴ According to Raytheon, even a cutting-edge Ku-band Radar Frequency System can only detect Class I UASs to a range of approximately sixteen kilometers.³⁵ For a small, commercial sUAS moving at maximum speed, this equates to a reaction time of less than thirteen minutes.³⁶ For the Iranian-built Shahed-136, this time shrinks to just six minutes.³⁷ If the situation is clear and unambiguous, this is plenty of time to make a decision and react, but with the introduction of just a little friction, this limitation in detection capability could have lethal consequences.

³¹ ATP 3-01.81, *Counter-Unmanned Aircraft System (C-UAS)*, 2-1.

³² Integrated Fires Rapid Capabilities Office, "LIDS [Low, Slow, Small UAS Integrated Defeat System] Family of Systems" (Huntsville, AL: Integrated Fires Rapid Capabilities Office, 2021), 5, <https://www.srcinc.com/pdf/LIDS-Family-of-Systems-Brochure.pdf>.

³³ Shaan Shaikh, Tom Karako, and Michelle McLoughlin, *Countering Small Uncrewed Aerial Systems: Air Defense by and for the Joint Force* (Washington, DC: Center for Strategic and International Studies, November 2023), 22, <https://www.csis.org/analysis/countering-small-uncrewed-aerial-systems>.

加劇這種情況的是，美軍在做出接戰決策的反應時間極為有限，這讓中東地區的敵手有可趁之機。美軍人員在討論中東地區的無人機反制行動時，往往提及最具挑戰性的部分是接戰決策必須在短短幾分鐘內下達。³⁴根據雷神公司指出，即使是最先進的 Ku 波段雷達頻率系統，也只能在 16 公里左右的距離內偵測到第一類無人機。³⁵若一架小型商用無人機以高速方式飛行，這代表反應時間不到 13 分鐘，³⁶若以伊朗製的「見證者-136」無人機為例，這個反應時間更是縮短到只剩下 6 分鐘。³⁷雖然在事實明確又無疑慮情況下，這段時間足以做出決策並採取行動，但只要出現一點磨擦或是干擾情事，一旦讓這項偵測能力遭受限制，可能就會發生致命後果。

sUAS Smuggling on the Southern Border of the United States

The southern border provides yet another valuable example of sUAS infiltration. Although not a traditional military example, the use of both manned and unmanned varieties of low, slow, small aircraft by transnational criminal organizations for over a decade to smuggle contraband and people into the United States makes this case an exceptionally well-developed game of cat and mouse. Most of these aircraft cross the border to provide surveillance on U.S. Border Patrol (USBP) positions and guide illegal migrants across the border. A smaller number carry contraband such as fentanyl-based drugs.³⁸ Unlike the isolated bases in the Middle East, sUAS infiltrations on the southern border exemplify the challenges of protecting an extended region. Additionally, in contrast to the large-scale combat operations in Ukraine, this case shows how the nuances of a gray-zone environment provide additional opportunities for sUAS infiltrations. However, like belligerents in Ukraine and the Middle East, transnational criminal organizations still employ the same tactical logics.

美國南部邊境的小型無人機走私行為

美國南部邊境提供另一個 sUAS 滲透的寶貴案例，雖然這並不是一個傳統的軍事案例，但跨國犯罪組織十多年來持續利用有人飛行器與低空、慢速及小型無人機，把人與違禁品偷運進美國，這個案例已成為一場貓抓老鼠的遊戲。大部分的有人與無人機穿越邊境，目的是監視美國邊境巡邏隊的位置，並引導非法移民偷渡，少部分的

³⁴ U.S. Army senior noncommissioned officer (NCO), interview with author, 22 January 2024. 美陸軍資深士官接受本文在 2024 年 1 月 22 日的訪談時提及。

³⁵ Paolo Valpolini, "Raytheon: C-UAS Capabilities Move to The Next Level," *European Defense Review* (website), 17 September 2019, <https://www.edrmagazine.eu/raytheon-c-uas-capabilities-move-to-the-next-level>.

³⁶ "Specs: DJI Mavic 3 Classic," Da-Jiang Innovations (DJI), accessed 16 August 2024, <https://www.dji.com/mavic-3-classic/specs>.

³⁷ "Shahed-136 Iranian Loitering Munition Unmanned Aerial Vehicle (UAV)," Operational Environment Data Integration Network (ODIN), accessed 19 August 2024, <https://odin.tradoc.army.mil/Search/WEG/shahed-136>.

則用來走私含有芬太尼的毒品。³⁸不同於美軍在中東地區的基地是各自獨立空間，美國南部廣大邊境區面對的是 sUAS 更容易滲透進來。此外，對比烏克蘭的大規模作戰行動，這個場景顯示灰色地帶環境的特性，也就是讓 sUAS 滲透有更多可資利用的空間。然而，如同烏克蘭與中東地區의 交戰方一樣，跨國犯罪組織依然會運用相同的戰術邏輯。

From a technical perspective, transnational criminal organizations exploit that the USBP cannot employ cutting-edge C-UAS technology capable of apprehending sUASs. The USBP's Rio Grande Valley sector has detected thousands of sUAS along its 227-mile border. Yet, the USBP has only been able to mitigate a fraction of these aircraft.³⁹ It is a daunting problem. Conversations with USBP C-UAS personnel reveal that the majority of these aircraft are commercial sUASs manufactured by Da-Jiang Innovations, which broadens the options available to detect them, but engagement methods must adhere to restrictions designed to limit collateral damage that could impact the local civilian population.⁴⁰ As a result, methods such as jamming, GNSS spoofing, and kinetic means are seldom employed.⁴¹ This provides criminal elements with considerably more flexibility. Although criminal organizations are exploiting a technical advantage in a strict sense (Tactic 1.1), they are actually benefiting from what the military would describe as stringent rules of engagement (ROE).

從技術觀點來看，跨國犯罪組織正是利用美國邊境巡邏隊無法有效部署反制無人機技術來攔截 sUAS 這個弱點。美國邊境巡邏隊在里奧格蘭德山谷的轄區，雖然已在其 227 英哩邊境上偵測到數千架 sUAS，但棘手的問題是，只有辦法對其中一小部分進行有效應對。³⁹從與美國邊境巡邏隊反制無人機人員的對話得知，這些飛行器大多是中國製的大疆創新商用 sUAS，雖然他們有很多方法可用來偵測該類無人機，但在採取攔截行動時仍必須遵守某些限制，以避免對當地平民造成附帶損害，⁴⁰在種情況下導致像是干擾、全球導航衛星系統欺騙，以及動態擊落等鮮少被採用，這讓犯

³⁸ "Human Smugglers Now Using Drones to Surveil USBP," U.S. Customs and Border Protection (USBP) media release, 1 March 2023, <https://www.cbp.gov/newsroom/local-media-release/human-smugglers-now-using-drones-surveil-usbp>; Tim Wright, "How Many Drones Are Smuggling Drugs across the U.S. Southern Border?," *Smithsonian Magazine* (website), June 2020, <https://www.smithsonianmag.com/air-space-magazine/narcodrones-180974934/>.

³⁹ *On the Front Lines of the Border Crisis: A Hearing with Chief Patrol Agents Before the Committee on Oversight and Accountability*, 118th Cong. (7 February 2023) (statements of John Modlin, Chief Patrol Agent, U.S. Border Patrol Tucson Sector; and Gloria Chavez, Chief Patrol Agent, U.S. Border Patrol Rio Grande Valley Sector), <https://www.congress.gov/event/118th-congress/house-event/115281/text>; U.S. Department of Homeland Security (DHS), *Fiscal Year 2024 Congressional Budget* (Washington, DC: DHS, 13 March 2023), 43, https://www.dhs.gov/sites/default/files/2023-03/DEPARTMENT%20OF%20HOMELAND%20SECURITY%20OVERVIEW_Remediated.pdf.

⁴⁰ USBP C-UAS agents, interview with author, 11 May 2023.

罪分子有更多操作的空間。⁴¹從嚴格意義上來說，犯罪組織是利用技術上優勢（戰術邏輯 1.1），但實際上，他們是從嚴格的交戰規則中獲益。

When these criminal elements use an opponent's ROE to their advantage, they impose an engagement dilemma (Tactic 2.1). Furthermore, this dilemma is not artificial. The legal requirements and use-of-force restrictions that underpin USBP engagement options exist for a reason. These rules must balance aircraft safety, commercial use of the electromagnetic spectrum, the public's right to safety, and other factors with the need to prevent illegal sUAS use. Criminals benefit from these restrictions by exploiting aircraft that are difficult to engage under our current standards for safety. They also do not exhibit obvious hostility that would trigger clear exceptions to use-of-force restrictions. This is not to say that these rules do not need serious adjustment—given the scope of the problem, the UBSP probably needs the authority to incorporate these technologies in a more flexible, case-by-case way. But even after the United States increases the countermeasures available, there will always be some exploitable margin inherent in the ROE. Therefore, the byproduct of any need to employ force selectively is a corresponding gap that spies, terrorists, and insurgents can exploit. This is true in wartime, but it is especially true in peaceful conditions in which the interests of commerce and public safety take on added weight.

當這些犯罪分子利用交戰規則來謀取自身利益時，美國邊境巡邏隊反而陷入一種交戰困境（戰術邏輯 2.1），這種困境是源自一套法律要求的合法性與使用武力限制，這些法規構成美國邊境巡邏隊行動選項的基礎，可是這些法規應在保障飛機安全、商業電子頻譜使用，以及防止非法 sUAS 等要求之間取得平衡，不然犯罪分子就會鑽現行安全標準的漏洞，從中操作那些邊境巡邏隊難以處理的飛行器，再加上他們的行為往往不具明顯敵意，並無法動用使用武力限制中明定的例外條款。鑑於問題的嚴重性，不得不嚴正看待這些法規並加以修定，美國邊境巡邏隊需要更大的職權彈性，才能依各自情況採用相對應的措施。然而，即使美國強化可用的反制措施，交戰規則仍存在一些可被利用的罅隙，由此可見，凡是出現需要選擇性使用武力的情況，其副作用就是會形成可被間諜、恐怖分子和叛亂分子所利用的漏洞。這種情況在戰時是如此，在平時更是明顯可見，亦凸顯吾人平時在商業利益與公共安全省思的重要性。

⁴¹ *The Preventing Emerging Threats Act of 2018: Countering Malicious Drones: Hearing on S. 2836 Before the Committee on Homeland Security and Governmental Affairs*, 115th Cong. (6 June 2018) (statements of David J. Glawe, Under Secretary for Intelligence and Analysis, DHS; and Hayley Chang, Deputy General Counsel, DHS), 103, <https://www.govinfo.gov/content/pkg/CHRG-115shrg34314/pdf/CHRG-115shrg34314.pdf>.

Criminal groups conducting sUAS infiltrations across the U.S. border are also skilled at compressing USBP reaction times (Tactic 2.2) and using mass employment (Tactic 2.3) to divide limited U.S. government detection resources. During any given hour along the border of the Rio Grande Valley sector, agents may detect several different sUASs on the Mexican side of the border, often simultaneously. Although the detection coverage is quite good in this sector, C-UAS agents must choose exactly where to employ their limited engagement options that cannot cover the entire border. Because these detections can be miles apart, this creates a difficult resource allocation problem that provides opportunities for sUAS operators to take advantage of displaced C-UAS capabilities. Additionally, many sUASs conduct surveillance from the Mexican side of the border without ever attempting infiltrations. This situation forces USBP personnel to decide which aircraft may attempt infiltration before committing C-UAS resources. Moreover, most sUAS flights start from concealed locations just meters from the border and often involve relatively short flights, further limiting the time available for C-UAS personnel to decide and react.⁴²

犯罪集體在跨境操作 sUAS 滲透時，擅於壓縮美國邊境巡邏隊的反應時間（戰術邏輯 2.2），還會以大規模部署（戰術邏輯 2.3）方式來分散美國有限的偵測資源。例如在里奧格蘭德山谷的轄區中，巡邏員在每小時內可能就會於墨西哥一側發現多架不同的 sUAS。雖然該轄區的偵測覆蓋範圍相當良好，但反制無人機巡邏員仍必須精準選擇在哪些地點使用他們有限的攔截手段，因為目前這些手段並無法涵蓋整條邊境。由於各個偵測點可能相距數英哩，形成一個棘手的資源配置問題，這讓 sUAS 操控者可以趁機利用反制無人機能力被調離空檔進行滲透。此外，許多 sUAS 只會在墨西哥一側從事監視，並不會嘗試越境滲透，這種情況迫使美國邊境巡邏隊必須在分配無人機反制資源前，正確判斷出哪些無人機具滲透意圖。最後一點，大多數 sUAS 都是從距邊境僅數公尺的隱蔽地點起飛，飛行距離通常相對較短，進一步壓縮反制無人機巡邏員的決策與反應時間。⁴²

Conclusion

Across Ukraine, the Middle East, and the southern border of the United States, sUASs use tactical art to bypass sophisticated defenses and access contested or denied areas. Although technology is a critical component of these tactics, it is not sufficient. Instead, sUAS infiltrations must also fly in ways that avoid the principal

⁴² USBP C-UAS agents, interview with author, 12 May 2023.

defensive measures of their adversaries (Tactical Logic 1). Less obviously, sUAS infiltrations must use the tactical situation and its inherent characteristics to impose uncertainty and dilemmas on their opponents (Tactical Logic 2). These basic tactical logics hold true in diverse conditions, including large-scale combat operations, base security in remote locations, and situations short of open military conflict. Training should acknowledge the psychological aspects of sUAS tactics as an inherent quality as important as the physical domain.

結論

在烏克蘭戰場、中東地區及美國南部邊境，sUAS 在戰術藝術的運用下繞過先進的防禦系統，滲透入爭奪區或是阻絕區。雖然科技是這些戰術行動中的關鍵要素，但單憑科技仍不足以達成目的，sUAS 滲透行動還要以能避開對方主要防禦措施的方式飛行（戰術邏輯 1）。較不為人察覺的是，sUAS 滲透會透過戰術局勢來借力使力，以向對方施加戰場不確定性與決策困境（戰術邏輯 2）。本文提出的戰術邏輯，基本上在各種情境下都適用，包含大規模作戰行動、偏遠地區的基地防禦，以及未達全面軍事衝突的情境，而且我們在訓練過程中應認知 sUAS 戰術邏輯中蘊含的思維理則，應視為與實務操作一樣同等重要。

Further efforts to understand sUAS infiltrations should focus on understanding how the approaches in the table interact with the operational environment. Field Manual 3-90 acknowledges that tactics must be matched appropriately with the mission variables and operational conditions.⁴³ Just as doctrine may employ armor units differently in an open desert versus dense urban terrain, sUASs exhibit the same nuance, some of which can be gleaned from the different examples presented here. For one, sUAS infiltrations may benefit from situations with larger public safety or civilian infrastructure concerns because of opportunities to exploit dilemmas and uncertainty (Tactical Logic 2). This is far more likely in gray-zone conditions than in large-scale combat operations. Urban areas, in particular, may offer more dilemmas for commanders employing C-UASs because public services increasingly rely on the radio frequency spectrum and GNSS services.⁴⁴ Urban areas also play to the physical logic of sUAS infiltration by inhibiting the line of site necessary for most C-UAS equipment and generating higher levels of electromagnetic clutter, which complicates detection efforts.⁴⁵ Although areas with high population density make standard ground infiltration techniques difficult due to the threat of compromise by civilian bystanders, recent research on the locations of sUAS infiltrations across the

southern border of the United States suggest the same rules do not apply in the air littoral.⁴⁶

至於要進一步了解 sUAS 的滲透行動，應著重於戰術邏輯表中所列各項與作戰環境之間的互動關係。第 3-90 號野戰手冊表明，戰術運用要根據任務變數與作戰條件做適當調整，⁴³誠如該手冊指出，裝甲部隊在開闊沙漠與密集城鎮地形的戰術運用有所不同，同樣道理，sUAS 也展現出這種細微差異，不同之處可以從本文案例中一窺究竟。sUAS 的滲透行動將從涉及公共安全或民用基礎設施的情境中受益，因為這些情境提供可資利用的困境與不確定性（戰略邏輯 2），相較於大規模作戰行動，這類情境在灰色地帶條件下更有可能發生，尤其在城鎮區，指揮官在運用無人機反制手段時可能會面對更多困境，因為公共服務日益依賴無線電頻譜與全球衛星定位系統。⁴⁴城鎮區也符合 sUAS 滲透的物理邏輯，因為其中建築物阻礙多數反制無人機系統所需視線，並產生高度的電磁雜訊，進一步增加偵測的困難度。⁴⁵雖然人口高密度區可能會因為被平民目擊而讓滲透行動變得更為困難，但近期針對美國南部邊境 sUAS 滲透地點的研究顯示，同樣規則並不適用於空中近岸區。⁴⁶

What does the tactical logic of sUAS infiltration mean for C-UAS efforts? There are several broad implications. First, C-UAS forces must use intelligence and act on it aggressively. The pressure placed on decision-making processes through uncertainty, dilemmas, and compressed reaction time requires commanders to place more emphasis on intelligence as a warfighting function. This effort requires thoughtful analysis and the constant fusion of all available sensors and collection platforms. Because sUASs can fly almost anywhere, commanders may be tempted to look everywhere. Given resource constraints, this strategy may not be feasible. Instead, intelligence efforts should focus collection and analysis on specific times and areas. Narrowing these efforts will require an understanding of the tactical art that is equal to or surpasses those attempting sUAS infiltration. By focusing efforts prior to launch or farther out along expected avenues of approach, commanders buy back valuable response time.⁴⁷

⁴³ FM 3-90, *Tactics*, 1-1.

⁴⁴ David Kilcullen and Gordon Pendelton, "Future Urban Conflict, Technology, and the Protection of Civilians: Real-World Challenges for NATO and Coalition Missions" (Washington, DC: Stimson Center, 10 June 2021), 8, 16, <https://www.stimson.org/2021/future-urban-conflict-technology-and-the-protection-of-civilians/>.

⁴⁵ J. B. Billingsley, *Low-Angle X-Band Radar Ground Clutter Spatial Amplitude Statistics*, Technical Report 958 (Lexington, MA: Lincoln Laboratory, Massachusetts Institute of Technology, 20 December 2002), 65, 113, <https://apps.dtic.mil/sti/pdfs/ADA410042.pdf>.

⁴⁶ Nathaniel Martins and Joel Vinson, "Low, Slow, and in the Clutter: Applying Lessons Learned from the U.S. Southern Border to SOF Aerial Infiltration" (Monterey, CA: Naval Postgraduate School, 2023), 120.

至於 sUAS 滲透的戰術邏輯對無人機反制行動意味著什麼？在此本文提出幾個廣泛的影響。第一，反制無人機部隊必須運用情報並積極採取行動。由於不確定性困境、兩難處境及反應時間被壓縮等因素，形成決策過程的壓力，所以指揮官必須更加重視情報作為這項作戰職能。該作為需要縝密的分析，以及持續整合所有可用感測器與情蒐平臺。由於 sUAS 幾乎可以在任何地點飛行，指揮官可能會傾向無差別地監控所有區域，但囿於資源有限，這種作法可能無法實行。至於情報作為應置重點於特定時間與區域的蒐集與分析。要有效聚焦於行動，吾人必須具備相當甚或超越 sUAS 滲透者的戰術素養，也就是將行動聚焦於無人機起飛前或預期敵接近路線的遠端，以利替指揮官爭取寶貴的反應時間。⁴⁷

Second, because sUAS infiltration benefits from intelligence, deception must be a critical component of C-UASs as well. Deception should include decoy targets such as those used by Ukrainians and the camouflage methods recommended in ATP 3-01.81, Counter-Unmanned Aircraft System (C-UAS).⁴⁸ This effort might also include changing the configuration of C-UAS equipment to reduce predictable vulnerabilities in a manner similar to random antiterrorism measures. Changing the configuration of C-UAS equipment would inhibit mass employment of successive (but not necessarily simultaneous) sUASs by making it difficult for adversaries to systematically probe defenses.

第二，sUAS 滲透需要靠情報支援，所以反制無人機系統必須將欺敵行動當成關鍵的一部分。欺敵行動應包含像是烏克蘭軍隊所使用的誘餌目標，以及美陸軍技術出版品第 3-01.81 號《反制無人機系統》所建議的偽裝方法。⁴⁸另還能以變更反制無人機系統的裝備配置，以減少其被預測的弱點，就像反恐的隨機策略一樣，讓人摸不著頭緒。調整反制無人機系統的裝備配置，將能抑制敵方 sUAS 的連續性（但不一定同時）大量部署，因為這將使其難以系統性試探我方的防禦弱點。

Third, both sUAS and C-UAS technical development should focus on enhancing the military's ability to apply the tactical logic of sUAS infiltrations outlined in this article. The cheap, mass employment of sUASs means that engagement options must be even cheaper. This is the promise of directed energy weapons. Engagement dilemmas, collateral damage, and fratricide means that this same technology must also be precise and reliable. Remote sensing efforts should focus on ways to correlate information from a variety of existing systems and

⁴⁷ Senior NCO, interview.

⁴⁸ ATP 3-01.81, *Counter-Unmanned Aircraft System (C-UAS)*, 3-1.

manufacturers (including those not originally designed for C-UASs) to make the intelligence picture as clear as possible.⁴⁹ Investments in one-stop-shop sensor systems like the Low, Slow, and Small UAV Integrated Defeat System are useful, but the former approach may reap better rewards in the long run as technology changes and acquisitions shift focus to other products over time.

第三，sUAS 攻防的技術發展，應將重點置於提升部隊對 sUAS 滲透戰術邏輯之運用，並依據本文的思維理則來實施。由於 sUAS 成本低又可大量部署，這代表攔截手段的成本要更低才行，這種時候導能武器就可以派上用場。然而，考量交戰困境、附帶損害及誤傷友軍的風險，無人機攻防技術必須具備高精確性與可靠性。遙控感測作業應著重於整合來自各種現有系統與製造商，包含有些系統一開始不是為反制無人機而設計，如此才能提升情資畫面的清晰度。⁴⁹雖然「低空、慢速、小型無人機整合打擊」這類單站式系統的投資有其價值，但隨著技術演進與採購重點品項逐漸轉移，上述整合多項來源的作法，長期看來可能會帶來更大效益。

Fourth, although the requirement to fuse capabilities from a variety of platforms may suggest the centralization of C-UAS efforts, local commanders must retain disciplined initiative. Hierarchical decision-making models will be too slow to address engagement decisions on compressed timelines. Current air defense doctrine already recognizes this reality by placing engagement decisions closer to the lower echelon executing element.⁵⁰ Yet lower-echelon commanders will also need the flexibility to cross-level ammunition and reposition systems dynamically. This requirement is more subtle and current doctrine does not recognize this level of agility.⁵¹ Yet with the high cost of engagement options like the Coyote interceptor, sUAS infiltrations can overload defenses faster than traditional hierarchical approval processes.⁵²

第四，雖然整合來自各種平臺的能力將促使反制無人機行動趨於集中指揮，但當地指揮官仍必須維持有紀律的主動作為。科層式決策模式在面對壓縮時間下的交戰決策時顯得遲緩，現行防空作戰準則已認知此一現實，故將交戰決策權下放至執行作戰的基層單位。⁵⁰因此，基層指揮官要具備在作戰中靈活調配彈藥與即時重新部署系統的能力，由於這部分屬於比較細部的要求，現行作戰準則尚未提及這種靈活性面向。⁵¹另外，一些問題像是「郊狼」這類反制無人機攔截器的交戰成本高昂，以及 sUAS

⁴⁹ Dan Gouré, "Defeating Small Drones: The U.S. Army's Next Big Challenge," RealClearDefense, 18 March 2021, https://www.realcleardefense.com/articles/2021/03/18/defeating_small_drones_the_us_armys_next_big_challenge_768769.html.

⁵⁰ FM 3-01, *U.S. Army Air and Missile Defense Operations* (Washington, DC: U.S. GPO, 2020), 2-2.

⁵¹ *Ibid.*, 1-6.

滲透速度往往比傳統層層批准的流程還要快，讓防禦系統根本來不及應對。⁵²

Finally, if sUAS infiltration is more than employing superior technology, C-UAS is also more than a scramble to get the best equipment—it is also a race to develop the best tactics. The C-UAS strategy acknowledges this fact through lines of effort directed at training and doctrine.⁵³ Of course, tactical art is far more than the concepts outlined in this article. Ultimately, tactical competence is a product of either (1) the back-and-forth struggle experienced in war or (2) realistic training conditions. This is the basic premise of the National Training Center. Opportunities to experiment with C-UAS methods of employment will benefit from difficult and realistic adversaries that employ the tactical logic outlined in this article. Given the role that the operational environment plays in the tactical art, force-on-force exercises and testing may need to abandon the sterile, desert environment of the National Training Center, White Sands Missile Range, or Yuma Proving Grounds in favor of more complicated urban environments.

最後，如果說 sUAS 滲透行動不僅是憑藉優越技術，則反制無人機行動也就不僅是競相取得最先進的設備，更是一場發展最佳戰術的競賽。反制無人機行動戰略其實已意識到這點，也透過強化訓練與作戰教範來應對。⁵³當然，戰術藝術不只是本文所闡述的概念，歸根究柢，戰術能力養成來自於下列兩者：一是戰爭中反覆的實戰較量；二是仿真的訓練環境，這正是美國國家訓練中心的基本理念。在既困難又逼真的敵情環境下演練，再加上運用本文所提的戰術邏輯表，將有助於驗證反制無人機的各種手段。鑑於作戰環境在戰術藝術中扮演關鍵的角色，兵力對抗演習與各項測試應捨棄國家訓練中心、白沙飛彈靶場、尤馬實驗場這類單純的沙漠環境，轉而選擇較為複雜的城鎮區。

The tactical art of sUAS infiltration and C-UAS remain just one part of warfare, and success in the air littoral will depend on a combination of internal and external factors. However, as the late strategist Colin Gray acknowledged, “strategic utility rests upon tactical feasibility,” and sUASs show us that tactical feasibility cannot simply be bought with better technology.⁵⁴ With the right tactical application, sUASs provide a tool of strategic proportions to infiltrate areas that are otherwise denied or accessible only at great cost. Because this tool is available to everyone, whoever masters the tactical logic of sUAS infiltrations will reap offensive and defensive

⁵² Harper, “Army Buys 600 Additional Coyote Counter-Drone Weapons.”

⁵³ DOD, *Counter-Small Unmanned Aircraft Systems Strategy*.

rewards.

無人機攻防的戰術藝術只是戰爭中一個面向，而且要在空中近岸區脫穎而出，取決於內外部眾多因素的作用。然而，誠如已故戰略家柯林·格雷所言，「戰略效用取決於戰術可行性」，sUAS 的實務運作向我們說明，戰術可行性並不能只靠提升技術來獲得。⁵⁴唯有正確運用戰術邏輯，才能讓 sUAS 成為一種具戰略影響力的工具，進而滲透那些阻絕區或須付出極大成本才能進入的區域。sUAS 這類工具取得容易，但誰能掌握 sUAS 滲透的戰術邏輯，誰才能在進攻與防守上佔據上風。

譯後語

自 2020 年納卡衝突的無人機攻擊事件以來，無人機攻防運用已引起軍方的關注與重視，無人機發揮的不對稱戰力，以小博大，已成為戰爭中的重要角色之一。然而，當世人都將無人機攻防重點置於技術面向時，本文提出另一個思維理則，認為技術需要配合有效的運用概念，才能在戰場上克敵制勝；鑑此，本文提出無人機滲透的戰術邏輯表，內容區分實體面與認知面共計八項的戰術邏輯，同時輔以烏克蘭戰場、中東地區及美國南部邊境實際案例，說明應如何運用這個戰術邏輯表。值此國軍無人機積極建置、擴編無人機專責部隊量能之際，本文所提無人機滲透的戰術邏輯表與實例說明可供相關單位參考，藉此提升無人機部隊戰力。

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⁵⁴ Colin S. Gray, "Handfuls of Heroes on Desperate Ventures: When Do Special Operations Succeed?," *Parameters* 29, no. 1 (Spring 1999): 2–24, <https://press.armywarcollege.edu/parameters/vol29/iss1/4/>.