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APPENDIX TO "WHY DRONES HAVE NOT REVOLUTIONIZED WAR"

This is the online appendix for the article Antonio Calcara, Andrea Gilli, Mauro Gilli, Raffaele Marchetti and Ivan Zaccagnini, "Why Drones Have Not Revolutionized War: The Enduring Hider-Finder Competition in Air Warfare," *International Security* Vol. 46, N. 4 (Spring 2022), pp. 130-171.

This appendix contains additional bibliographic and explanatory material for the article that, for space reasons, we could not include in the printed version. The bibliographic and explanatory material presented below is organized numerically, with each number corresponding to the footnote in the printed article.

Footnote 2: See also Gregoire Chamayou, A Theory of the Drone (New York, NY: The New Press, 2015); and Andreas Krieg and Jean-Marc Rickli, *Surrogate Warfare: The Transformation of War in the Twenty-First Century* (Washington, DC: Georgetown University Press, 2019).

Footnote 10: Specifically, Zegart writes, for "coercion, this means that threats from a drone state, if carried out, are more likely to be continued over the long term." Zegart, "Cheap fights, Credible Threats," p. 18

Footnote 15: See also Klaus Schwab, *The Fourth Industrial Revolution* (New York, NY: Crown Business, 2016).

Footnote 17: Given the role of the electro-magnetic spectrum in this competition, a more accurate name would be sensing and counter-sensing competition. We would like to thank Reviewer 3 for suggesting this point. We prefer hider-finder competition because it is more intuitive and it connects this competition to the one between innovations and counter-innovations. With regard to the sensing and counter-sensing competition, the Soviet Union was one of the first countries to fully appreciate the importance of the electro-magnetic spectrum. Admiral Gorshkov, after observing Israel's reliance on jamming to degrade Syrian guided missiles in the Yom Kippur war concluded that "the next war will be won by the side that best exploits the electromagnetic spectrum." See Robert b. Bathurst, *Understanding the Soviet Navy: A Handbook* (Newport, R.I.: Naval War College Press, 1979), p. 127.

Footnote 20: These classifications are drawn from NATO Standardization Agreement 4670—NATO's guidance for training drone operators.

Footnote 22: See also Benjamin Lambeth, *Air Operations in Israel's War against Hezbollah. Learning from Lebanon and Getting It Right in Gaza* (Santa Monica: RAND Corporation, 2011); Jenna Jordan, "The Effectiveness of the Drone Campaign against Al Qaeda Central: A Case Study." *Journal of Strategic Studies* 37, No. 1 (2014): 4–29; Patrick B. Johnston and Anoop K. Sarbahi, "The Impact of U.S. Drone Strikes on Terrorism in Pakistan," *International Studies Quarterly*, Vol. 60, No. 2 (June 2016), pp. 203–219; and Michael Kreuzer, *Drones and the Future of Air Warfare. The Evolution of Remotely Piloted Aircraft* (Abingdon, UK: Routledge, 2017).

Footnote 30: Some analysts and observers predict that "all armed forces in the world will use UAVs" and that "every country on earth will be able to build or acquire drones capable of firing missiles within the next ten years." See respectively, Ulrike E. Franke, "Military Robots and Drones," in Galbreath, D. J. and J. R. Deni (eds.), *Routledge Handbook of Defence Studies* (London:

Routledge, 2018), p. 341; and Peter Tucker, "Every Country Will Have Armed Drones Within 10 Years," *Defense One* (May 6, 2014).

Footnote 32: Some, for example, note that "an army of robots can entrench US power without humans on the ground." Ian G.R. Shaw, "Robot Wars: US Empire and Geopolitics in the Robotic Age," *Security Dialogue*, Vol. 48, No. 5 (October 2017), p. 458, https://doi.org/10.1177/0967010617713157.

Footnote 38: After our article went to press, we realized that Michael Kreuzer had had the same intuition we develop in our article, but much earlier than we did. In his dissertation from 2014, Kreuzer linked the use of drones to Biddle's modern system of force employment. To our knowledge, this is the first work that applied Biddle's framework to the operational use of drones. When citing our article, please also cite Kreuzer's dissertation. That Kreuzer, at that time a PhD student at Princeton and a Major in the U.S. Air Force, proposed the same intuition we do enhance our confidence in our framework. In particular, Kreuzer wrote: "While strategic [Remotely Piloted Aircraft] are revolutionary in their impact, the vast majority of RPAs both currently employed and likely to diffuse in the future will be tactical RPAs, which are much less a game-changer than the more well recognized strategic RPAs. Tactical RPAs have been integrated into many militaries worldwide over the past three decades, have been used in numerous conflicts, and while they have impacted those conflicts in terms of increasing collection capability they have not fundamentally altered the existing systems for land warfare. Cover, concealment, and small unit maneuver, which Stephen Biddle classified as the Modern System, still dominates the world of tactical RPAs. Tactical RPAs will be a force multiplier at the operational level of war given their relative expendability owing to the lack of a pilot and the low cost associated with the platform. Future RPAs could potentially extend some of the revolutionary implications of strategic RPAs to limited wars, but likely only as part of a system that can secure airspace control for a duration sufficient to allow for persistent operations. Several models put forward late in this volume, such as 'swarm and cloud' strategies." Michael P. Kreuzer, *Remotely Piloted Aircraft: Evolution, Diffusion, And the Future of Air Warfare* (Princeton, NJ: *PhD. Dissertation*, 2014). See also Kreuzer's subsequent book, which builds on his dissertation Michael P. Kreuzer, *Drones and the Future of Air Warfare: The Evolution of Remotely Piloted Aircraft* By (London, UK: Routledge, 2016), pp. 6 and 130.

Footnote 39: For a discussion of the firepower revolution, see for example John Ellis, *The Social History of the Machine Gun* (Baltimore, MD: The Johns Hopkins University Press, 1975), pp. 79-109 and 111-148; Daniel R. Headrick, *The Tools of Empire: Technology and European Imperialism in Nineteenth Century* (New York, Oxford University Press, 1981), pp. 83-126.

Footnote 42: See also Stephen D. Biddle and Robert Zirkle, "Technology, Civil-Military Relations, and Warfare in the Developing World," *Journal of Strategic Studies*, Vol. 19, No. 2 (June 1996), pp. 171–212; Stephen Biddle, "The Past as Prologue: Assessing theories of future warfare," *Security Studies* Vol. 8, No. 1 (1998), pp. 1-74; Stephen D. Biddle, *Afghanistan and the Future of Warfare: Implications for Army and Defense Policy* (Carlisle, Pa.: Strategic Studies Institute, U.S. Army War College, 2002); Stephen D. Biddle, and Stephen Long, "Democracy and Military Effectiveness: A Deeper Look." *Journal of Conflict Resolution* 48, no. 4 (August 2004): 525–46; and Stephen D. Biddle, "Speed kills? Reassessing the Role of Speed, Precision, and Situation Awareness in the Fall of Saddam," *Journal of Strategic Studies*, Vol. 30, No. 1 (2007), pp. 3-46; and Anthony King, The Combat Soldier Infantry Tactics and Cohesion in the Twentieth and Twenty-First Centuries (Oxford: Oxford University Press 2013), 24–39, 62–97.

Footnote 43: See also Norman Friedman, *Network-Centric Warfare: How Navies Learned to Fight Smarter Through Three World Wars* (Annapolis, MD: Naval Institute Press, 2009).

Footnote 45: For a discussion of this transformation, see for example Richard P. McMullen, "History of Air Defense Weapons, 1946–1962," *Air Defense Command Historical Study Number 14* (Historical Division, Office of Information, HQ Air Defense Command, 1963); Ralph Baldwin, *The Deadly Fuze* (San Rafael, Calif.: Presidio Press, 1980); John W. R. Lepingwell, Soviet Strategic Air Defense and the Stealth Challenge," *International Security* Vol. 14, No. 2 (Fall, 1989), pp. 64-100; Kenneth Schaffel, *The Emerging Shield: The Air Force and the Evolution of Continental Air Defense 1945-1960* (Washington, D.C.: Office of Air Force History, 1991); Lt. Col. Edward B. Westermann, *Defending Hitler's Reich: German Ground-Based Air Defenses, 1914-1945* (Chapel Hill, NC: PhD Dissertation University of North Carolina, 2000).

Footnote 46: See also Brungess, *Setting the Context*, pp. 1-50; Kenneth P. Werrell, *Archie to SAM*, pp. 69-112; and Steven J. Zaloga, *Soviet Air Defence Missiles: Design, Development and Tactics* (London, UK: Jane's Information Group, 1989), pp. 1-51.

Footnote 48: Jon Lindsay describes how also Al-Qaeda learned to use the modern system of force employment against American drone strikes. The paragraph is worth citing in full: "A June 2011 report by a militant calling himself Abdullah bin Mohammed summarizing lessons learned by al-Qaeda in Waziristan and discussed in a 'Military Research Workshop' held in Yemen turned up in a safe house in Timbuktu a year and a half later [...] Mohammed begins his report by pointing out that the chief advantage of drones is not military—the Americans have plenty of 'combat jets like the F16'—but political. Mohammed then discusses a range of denial and deception, electronic warfare, and defensive countermeasures to defeat drone operations. To defeat measurement, he recommends 'not to use permanent headquarters'; 'complete silence of all wireless contacts'; 'stay in places unlit by the sun such as the shadows of the buildings or the trees'; 'use smoke as cover by burning tires'; 'deceive the drone by entering places of multiple entrances and exits'; and 'Formation of fake gatherings such as using dolls and statutes to be placed outside false ditches to mislead the enemy.' To defeat coordination, he recommends hacking 'the drone's waves and the frequencies' with 'computer know-how' and 'Jamming...and confusing of electronic communication' by leaving mechanical equipment running. To defeat enforcement, he recommends 'well-placed reconnaissance networks...to warn all the formations to halt any movement in the area' and the use of 'skilled snipers to hunt the drone, especially the reconnaissance ones because they fly low.' Meetings should be held in 'underground shelters' or 'forests and caves' to 'avoid gathering in open areas'; and if 'a drone is after a car, leave the car immediately and everyone should go in different direction because the planes are unable to get after everyone.' As a U.S. Predator operator noted, 'These are not dumb techniques. It shows that they are acting pretty astutely'." Lindsay, *Information Technology and Military Power*, pp. 180-212.

Footnote 56: For simplicity in the text we have referred primarily to ground-based air defenses, but we want to emphasize that airborne sensors and shooters play a critical role in integrated air defense systems. These aircraft are Airborne Warning And Control System (AWACS) for early warning, and aircraft interceptors for prompt response and engagement. See *Electronic Warfare Fundamentals*, pp. 1.1–1.10.

Footnote 58: This is why the 1991 war in Iraq started with two American helicopters attacks on Iraqi early warning radar sites. See Thomas A. Keaney and Eliot A. Cohen, *Revolution in Warfare? Air Power in the Persian Gulf* (Annapolis, MD: Naval Institute Press, 1995), p. 10.

Footnote 62: The whole paragraph in Lambeth's book is worth quoting: "The dearth of enemy radar-guided SAM activity may also have been explainable, at least in part, by reports that the Air Force's Air Combat Command had been conducting information operations by inserting viruses and deceptive communications into the enemy's computer system and microwave net. Although it is unlikely that U.S. information operators were able to insert malicious code into enemy SAM radars themselves, General Jumper later confirmed that Operation Allied Force had seen the first use of offensive computer warfare as a precision weapon in connection with broader U.S. information operations against enemy defenses. As he put it, "we did more information warfare in this conflict than we have ever done before, and we proved the potential of it." Jumper added that although information operations remained a highly classified and compartmented subject about which little could be said, the Kosovo experience suggested that "instead of sitting and talking about great big large pods that bash electrons, we should be talking about microchips that manipulate electrons and get into the heart and soul of systems like the SA-10 or the SA-12 and tell it that it is a refrigerator and not a radar." Such pioneering attempts at offensive cyber- warfare pointed toward the feasibility of taking down SAM and other defense systems in ways that would not require putting a strike package or a HARM missile on critical nodes to neutralize them." Benjamin S. Lambeth, *NATO's Air War for Kosovo: A Strategic and Operational Assessment* (Santa Monica, Calif.: The RAND Corporation, 2001), p. 112. The quotations reported by Lambeth come, respectively, from David A. Fulghum, "Serb Threat Subsides, but U.S. Still Worries," *Aviation Week and Space Technology*, April 12, 1999, p. 24; and "Jumper on Air Power," *Air Force Magazine*, July 2000, p. 43.

For a discussion of US Air Force secret cyber-attack program tasked with degrading enemy's air defenses, see Joseph Trevithick, "America's Electronic Attackers May Have a Secret," *The Drive* (June 7, 2017), https://www.thedrive.com/the-war-zone/11252/americas-electronic-attackers-may-have-a-secret-mission.

For space constraints we have focused only on the cyber defense capabilities that air defense requires. In fact, it can also take advantage of cyber capabilities for taking down enemy aircraft. A prominent example, yet disputed, is the claims that Iran downed a US RQ-170 *Sentinel* with cyber means in 2011. See for example Scott Peterson, "Downed US drone: How Iran caught the 'beast'," *Christian Science Minotor* (December 9, 2011), https://www.csmonitor.com/World/Middle-East/2011/1209/Downed-US-drone-How-Iran-caught-the-beast; David Axe, "Nah, Iran Probably Didn't Hack CIA's Stealth Drone," *Wired* (April 24, 2012), https://www.wired.com/2012/04/iran-drone-hack/.

Footnote 63: See also Mike (Mihajlo) Mihajlovic and Djordjie S. Anicic, *Missileers Against Stealth: The First Downing of the Stealth Fighter in History* (Toronto, Canada: MSM Publishing, 2019), p. 208.

Footnote 64: Price has provided a much more extensive and technical history of the evolution of electronic counter-measures and counter-countermeasures in Alfred Prize, *The History of US Electronic Warfare Volume I: The Years of Innovation-Beginnings to 1946* (Alexandria, VI: Association of Old Crows, 1984); Alfred Price, *The History of US Electronic Warfare Volume II: The Reinassance Years 1946 to 1964* (Alexandria, VI: Association of Old Crows, 1989*;* Alfred Price, *The History of US Electronic Warfare Volume III: Rolling Thunder Through Allied Force, 1964 to 2000* (Alexandria, VI: Association of Old Crows, 2000). For an accessible introduction to electronic warfare, see for example Robert N. Lothes, Micheal. B. Szymanski, and Richard. G. Wiley, *Radar Vulnerability to Jamming* (Boston, MA: Artech House, 1990); For recent advances in electronic warfare, see for example Bryan Clark and Mark Gunzinger, *Winning the Airwaves: Regaining America's Dominance in The Electromagnetic Spectrum* (Washington, DC: Center for Budgetary and Strategic Assessment, 2015); Sydney J. Freedberg Jr., "Army Wants New Mega-Jammer In 2023: TLS-EAB," *Breaking Defense* (September 29, 2020), https://breakingdefense.com/2020/09/army-wants-new-mega-jammer-in-2023-tls-eab/; Sydney J. Freedberg Jr., "Super-Jammer Goes To Army Multi Domain

Task Force, *Breaking Defense* (July 27, 2021), https://breakingdefense.com/2021/05/super-jammer-goes-to-army-multi-domain-task-force/; Marcus Clay, "To Rule the Invisible Battlefield: The Electromagnetic Spectrum and Chinese Military Power," *War on the Rocks* (January 22, 2021), https://warontherocks.com/2021/01/to-rule-the-invisible-battlefield-the-electromagnetic-spectrum-and-chinese-military-power/; and "New tools for electronic warfare: multispectral operations and mission-adapting sensors," *Breaking Defense* (April 29, 2022), https://breakingdefense.com/2022/04/new-tools-for-electronic-warfare-multispectral-operations-and-mission-adapting-sensors/.

Footnote 65: See also Matthew Monte, *Network Attacks and Exploitation: A Framework 1st Edition*, (Indianapolis, IN: Wiley & Sons, 2015).

Footnote 68: Lack of proficiency can easily result in accidents, as the shooting down of a Malaysian Airlines airplane (MH17) over Ukraine in July 2014, and of a Ukraine International Airlines airplane (PS752) in Teheran in January 2020 show. See for example Stephen Biddle and Ivan Oelrich, "Why the Ukraine Separatists Screwed Up: Badly Organized Insurgents Can't Master Complex Weapons Systems," *Washington Post – Monkey Cage* (July 21, 2014); and Julian E. Barnes, Eric Schmitt, Anton Troianovski and Natalie Kitroeff "Iranian Missile Accidentally Brought Down Ukrainian Jet, Officials Say, Citing Early Evidence," *The New York Times* (January 2020). For discussions about the importance of skill and proficiency of air defense operators, see for example Marshall L. Michel III, *Clashes: Air Combat over North Vietnam 1965–1972* (Annapolis, MD: Naval Institute Press, 1997); Benjamin S. Lambeth, *NATO's Air War for Kosovo: A Strategic and Operational Assessment* (Santa Monica, Calif.: The RAND Corporation, 2001).

Footnote 69: See also Mihajlovic and Anicic, *Missileers Against Stealth*, pp. 210-221.

Footnote 73: Air defense systems can inflict different types of damage on an aircraft. What is important is that damage to many critical parts of an aircraft, including the engine, the wings, the external sensors, the instrument panel and commands, cables and electro-hydraulic transmissions, and of course the pilot can be sufficient to force an aircraft to abort the mission or to emergency land – to which one must add lethal damage that lead the aircraft to crash to the ground or to explode mid-air. For a discussion, see for example Matthew C. Waddell, *Surface-To-Air Guided Missile. Systems Methods of Tactical Analysis* (Silver Spring, MD: Johns Hopkins University – Physics Applied Laboratory, 1961), pp. 21-23; Phil Haun, "Air Power versus Ground Forces Deterrence at the Operational Level of War," in Eric Gartzke and Jon R. Lindsay (eds), *Cross-Domain Deterrence: Strategy in an Era of Complexity* (Oxford, UK: Oxford University Press, 2019).

Footnote 75: Since sensors (visual, thermal sensors, and electro-magnetic) receive aggregate information that contains either only ambient noise when the target is not present; or ambient noise and the signal generated by the target when the target is present, detection requires disentangling signal from the noise (for simplicity we use the term noise, even though we are referring to clutter – i.e., the unwanted return originating from airborne and ground scatterers different from the intruders). For a general discussion, see for example Francois Le Chevalier, *Principles of Radar and Sonar Signal Processing* (Norwood, MA: Artech House, 2002).

Footnote 78: The most known MANPADS are the American FIM-92 *Stinger*, the 9k32 *Strela*-2 (NATO reporting name: SA-7 Grail), and the 9M336 *Verba* (NATO reporting name: SA). They depend on an infra-red sensor that tracks heat emissions like engine exhaust, which in turn explains the limited range and altitude reach of these systems. See for example "US Army starts upgrade of FIM-92E Stinger Block I missiles," *Army Technology* 2 November 2014; "New Russian Air Defense System Gibka-S Works against Ultra-low Flying Threats," *Defense World* (December 26, 2019);

GlobalSecurity.org, "9M336 Verba (Willow)," https://www.globalsecurity.org/military/world/russia/9m336.htm

Footnote 82: Bronk, "Modern Russian and Chinese Integrated Air Defence Systems," and Chris Dougherty, "Moving Beyond A2/AD," *CNAS* (December 3, 2020).

Footnote 83: For a discussion of the challenges of maintaining stealth aircraft, see for example Bill Sweetman, *Inside the Stealth Bomber* (Minneapolis, MN: Zenith Press, 1999), pp. 109-120; and Gary Schaub Jr. and Hans Peter H. Michaelsen, *Integrating the F-35 into Danish Defence* (Copenhagen, Denmark: This University of Copenhagen Centre For Military Studies, November 2018).

Footnote 85: For a general discussion of several key cases, see Brungess, *Setting the Context*, pp. 1-50; and Dougherty, *Defense Suppression*, pp. 20-34.

Footnote 86: Airborne radars, patrolling aircraft and aircraft interceptors will make air penetration even more demanding and difficult. For a general discussion on data fusion, see for example David L. Hall and James Llinas "Multisensor Data Fusion," in Martin E. Liggins, David L. Hall and James Llinas (eds.), *Handbook of Multisensor Data Fusion: Theory and Practice – Second Edition* (Boca Ranton, FL: CRC Press, 2008), pp. 1-14.

Footnote 87: See also Jonathan House, *Toward Combined Arms Warfare: A Survey of Twentieth Century Tactics Doctrine, and Organization* (Fort Leavenworth, KS: U.S. Army Combat Studies Institute, 1984), p. 173. For an empirical discussion of the War in Iraq, see Eliot A. Cohen, *Gulf War Air Power Survey Vol. II: Operations and Effects and Effectiveness* (Washington, D.C.: Office of the Secretary of the Air Force, 1993), pp. 116-138. Eliot A. Cohen, *Gulf War Air Power Survey IV: Weapons, Tactics, and Training and Space Operations* (Washington, D.C.: Office of the Secretary of the Air Force, 1993), pp. 101-105 and 181-192. For a discussion of the War in Kosovo, see Tirpak, "Dealing with Air Defense," p. 26; Lambeth, "Kosovo and the Continuing SEAD Challenge;" Lambeth, *NATO's Air War for Kosovo*; and Rip and Hasik, *The Precision Revolution*, pp. 381-417; and Posen, "The War for Kosovo."

Footnote 90: The employment of EW to degrade enemy's radar dates back to World War II. During the Vietnam War, it became more extensively employed in coordination with strike aircraft, as a response to North Vietnam employing Soviet radars in its integrated air defense network. Defeating the North Vietnam's radar through EW became so demanding that, at one point, for every strike aircraft, there was a multiple supporting specialized EW aircraft. See for example Michel, *Clashes*; see for example C. R. Anderegg, *Sierra Hotel: Flying Air Force Fighters in the Decade after Vietnam* (Washington, D.C.: Air Force History and Museums Program United States Air Force, 2001); Alfred Price, *Instruments of Darkness: The History of Electronic Warfare, 1939–1945* (Barnsley, UK, Frontline Books, 2017); Alfred Price, *War in the Fourth Dimension: U.S. Electronic Warfare, From the Vietnam War to the Present* (London, UK: Greenhill Books, 2001); Robert J. Hanyok *Spartans in Darkness: American SIGINT and the Indochina War, 1945-1975* (Fort George, MD: National Security Agency - Central Security Service, 2002); Rip and Hasik, *The Precision Revolution*, pp. 19-34; James Goodall and Bill Sweetman, *Lockheed F-117A: Operation and Development of the Stealth Fighter* (Somerset, UK: Foulis, 1990), p. 18.

Footnote 91: See also Maj Gen Mark Barrett, USAF (Ret.) with Col Mace Carpenter, USAF (Ret.), *Survivability in the Digital Age: The Imperative for Stealth* (Arlington, VA: The Mitchell Institute for Aerospace Studies Air Force Association, 2017), p. 30; and John Paterson, "Technology's Effects on Combat Aircraft Survivability," *Journal of Aerospace* Vol. 106, No 1 (1997), pp. 1515-1530. On how the proficiency of pilots affects attrition rate, see for example Anderegg, *Sierra Hotel*, p. 14.

Footnote 92: See also Dougherty, *Defense Suppression*, pp. 24-27.

Footnote 105: Jalel Harchaoui of the Clingendael Institute noted that Turkey's use of its TB2 in Libya had been a "game changer" thanks to the Turkish capability to evolve and improve the performance of their drones. Cited in Tom, "Libya is turning into a battle lab for air warfare," *Defense News*.

Footnote 111: See also Pack and Pusztai, *Turning the Tide,* p. 5.

Footnote 113: For the LNA, we could not find any specific data about drones availability from multiple sources such as Bellingcat, RAND and IISS Military Balance 2018-2020. For this reason, we employed a conservative coding strategy, and we used data about all the drones acquired by UAE from China between 2010 and 2020, which amount to 15 in 2017 and 25 in 2018. See the SIPRI and ISPI data. https://www.ispionline.it/en/pubblicazione/middle-easts-game-drones-race-lethal-uavs-and-its-implications-regions-security-landscape-28902 The SIPRI Stockholm International Peace Research Institute claimed that China delivered 40 drones to the UAE in the period 2010-2020. For Gady the LNA had 8 Wing Loong I and "some" Wing Loong II. As a conservative coding, we assume "some" equal to 12. See Gady, *Useful, but not decisive,* and Bruce Einhorn, "Combat Drones Made in China Are Coming to a Conflict Near You", *Bloomberg*, March 17, 2021,
https://www.bloomberg.com/news/articles/2021-03-17/china-s-combat-drones-push-could-spark-a-global-arms-race

Footnote 114: See also Pack and Pusztai, *Turning the Tide*, p. 4-5.

Footnote 115: See also Pack and Pusztai, *Turning the Tide,* pp. 4-14.

Footnote 117: See also Feridun Taşdan, "Turkish EW Systems: The Unseen Force Behind Recent Turkish Drone Successes," *Turkey Defense* Vol 15, No. 106 (2021), https://www.defenceturkey.com/en/content/turkish-ew-systems-the-unseen-force-behind-recent-turkish-drone-successes-4532;

Footnote 119: See also The International Institute for Strategic Studies (IISS), *The Military Balance 2020*, p. 365; Alex Gatopoulos, "'Largest drone war in the world': How airpower saved Tripoli", *Al Jazeera*, May 28, 2020, https://www.aljazeera.com/news/2020/5/28/largest-drone-war-in-the-world-how-airpower-saved-tripoli and Pack and Pusztai, *Turning the Tide*, p. 4. According to the IISS, "at least two UAE-owned Schiebel *Campopter* S-100 rotary UAVs have also been deployed, as well as an unknown number of Iranian-made *Mohajer*-2 UAVs". The *Wing Loong II* are responsible for the majority of the 800 strikes conducted by the LNA between April to November 2019.

Footnote 123: See also The Arab Weekly, "Reports shed light on mercenaries, terrorists sent by Turkey to Libya", *The Arab Weekly*, July 18, 2020, https://thearabweekly.com/reports-shed-light-mercenaries-terrorists-sent-turkey-libya. The Middle East Institute reported that "about 500 Syrians mercenaries had been killed and more than 2.000 wounded by June 2020", Pack and Pusztai, oppure Fishman and Hiney, *What Turned the Battle for Tripoli?,* https://www.washingtoninstitute.org/policy-analysis/view/what-turned-the-battle-for-tripoli.

Footnote 125: See also Pack and Pusztai, *Turning the Tide*, p. 9.

Footnote 130: See also Gianandrea Gaiani, "I turchi sbarcano a Tripoli artiglieria e cingolati da combattimento," *Analisi Difesa*, February 1, 2020, https://www.analisidifesa.it/2020/02/a-tripoli-i-turchi-sbarcano-artiglieria-e-cingolati-da-combattimento/

Footnote 132: See also Nikolaos Van Dam, *Destroying a Nation: The Civil War in Syria* (London: Bloomsbury Publishing, 2017); Robin Yassin-Kassab, and Leila Al-Shami, *Burning Country: Syrians in Revolution and War* (London: Pluto Press, 2018).

Footnote 135: See also Syria Mubasher, "Downing of a reconnaissance plane in the Qalamoun region 7-12-2013", last accessed June 25, 2021, https://www.youtube.com/watch?v=MyshPGpVo3Y; Hussam Al Marie, Twitter post May 16, 2015, https://twitter.com/HussamAlMarie/status/599585335522263040; Phil Stewart, "In Syrian Skies, U.S. Pilots Learn How Fast Air War Can Morph," *Reuters*, August 28, 2017, https://www.reuters.com/article/us-usa-syria-pilot-idUSKCN1B80CA. On US operations against Iranian drones see also Michael R. Gordon, "U.S. Says It Shot Down Drone That Attacked Fighters in Syria," *New York Times*, June 8, 2017, https://www.nytimes.com/2017/06/08/world/middleeast/syria-drone-shot-down.html, and Julian Borger, "US Shoots Down Second Iran-Made Armed Drone over Syria in 12 Days," *The Guardian*, June 20, 2017, https://www.theguardian.com/us-news/2017/jun/20/us-iran-drone-shot-down-syria.

Footnote 142: See also John Dorrian, "Department of Defense Press Briefing by Col. Dorrian via Teleconference from Baghdad, Iraq," transcript, *U.S. Department of Defense*, May 3, 2017, https://www.defense.gov/Newsroom/Transcripts/Transcript/Article/1172185/department-of-defense-press-briefing-by-col-dorrian-via-teleconference-from-bag/; Shawn Snow, "Marine Artillery Barrage of Raqqa Was So Intense Two Howitzers Burned Out", *Marine Corps Times*, November 2, 2017, https://www.marinecorpstimes.com/flashpoints/2017/11/02/marine-artillery-barrage-of-raqqa-was-so-intense-two-howitzers-burned-out/ ; and Don Rassler, *The Islamic State and Drones: Supply, Scale, and Future Threats* (West Point, NY: Combating Terrorism Center, 2018).

Footnote 146: See also Mason Clark, *The Russian Military's Lessons Learned in Syria* (Washington, DC: Institute for the Study of War, 2021).

Footnote 149: See also Van Dam, *Destroying a Nation*; and Christopher Kozak, "'An Army in All Corners': Assad's Campaign Strategy in Syria," *Middle East Security Report*, No. 26 (Washington, DC: Institute for the Study of War, 2015).

Footnote 150: See also United Nations High Commissioner for Refugees, "Syria Regional Refugee Response," *Operational Data Portal: Refugee Situations* (Geneva, UNHCR, 2021).

Foonote 167: Arie Egozi, "Armenia-Azerbaijan War Offers Valuable Lessons for Militaries Worldwide: An Analysis", *Raksha Anirveda* December 26, 2020, https://www.raksha-anirveda.com/armenia-azerbaijan-war-offers-valuable-lessons-for-militaries-worldwide-an-analysis/; According to Azerbaijan's president, Ilham Aliyev, Azerbaijani forces destroyed seven S-300 transporter erector launchers, two guidance stations, and one radar. https://ru.president.az/articles/48205 .

Footnote 169: Despite the Turkey deployed some obsolete systems like the MIM-23 Hawk in Libya, they were integrated into an efficient multilayered air-defense system along with modern anti-air guns like the Korkut SPAAG and supported by early warning radars and long-range air

defense systems established by frigates of the Gabya class. Furthermore, these systems have been employed following a well-structured Turkish concept of operation. Finally, the UAE deployed the state-of-the-art Russian-made Pantsir S1 SHORAD system. See Pack Jason and Pusztai Wolfgang, "Turning the Tide, how Turkey won the war for Tripoli", p.10.

Footnote 170: On the capabilities of the S-300-PMU2, see David K. Barton, "The 1993 Moscow Air Show," Microwave Journal Vol. 37, No. 5 (May 1994), p. 30. On the delivery of the first S-300 air-defense system to Armenia see Floriana Fossato, "Russia: Moscow Starts Delivery Of S-300 Missiles to Armenia", Radio Free Europe, (February 9, 1999), https://www.rferl.org/a/1090583.html. See also IISS, The Military Balance 2020, p. 183 and Military Watch Magazine, "S-300PT vs. S-300PMU-2: Why Azerbaijan Has the Air Defence Advantage Over Armenia" (September 20, 2020), https://militarywatchmagazine.com/article/s-300pt-vs-s-300pmu-2-why-azerbaijan-has-the-air-defence-advantage-over-armenia.https://www.rferl.org/a/1090583.html. See also IISS, The Military Balance 2020, p. 183 and Military Watch Magazine, "S-300PT vs. S-300PMU-2: Why Azerbaijan Has the Air Defence Advantage Over Armenia" (September 20, 2020), https://militarywatchmagazine.com/article/s-300pt-vs-s-300pmu-2-why-azerbaijan-has-the-air-defence-advantage-over-armenia.

Footnote 171: More generally, see David K. Barton, "Recent developments in Russian Radar Systems," *Proceedings International Radar Conference* (May 8-11, 1995), pp. 340-346; and V.S. Cherneyak, I.Ya. Immoreev, B.M. Vovshin, "Radar in the Soviet Union and Russia: A Brief Historical Outline," *IEEE Aerospace and Electronic Systems Magazine* Vol. 18, No. 12 (December 2003), p. 5.

Footnote 174: Despite the advantage of Azerbaijani's drones over Armenian air defense systems, media reported some video of Azeris UAVs downed by Yerevan rockets. See Avet Demourian, "Armenia says it shot down Azerbaijani drone near capital", *CTV News*, October 1, 2020, https://www.ctvnews.ca/world/armenia-says-it-shot-down-azerbaijani-drone-near-capital-1.5128978.

Footnote 200: See Demourian, "Armenia says it shot down Azerbaijani drone near capital."

Footnote 211: Because of the hider-finder competition and of the nature of the current wave of technological transformation, there is reason to believe that these requirements will acquire even greater salience in the future. For a more general discussion, see Biddle and Zirkle, "Technology, Civil-Military Relations, and Warfare in the Developing World;" Christopher S. Parker, "New Weapons for Old Problems: Conventional Proliferation and Military Effectiveness in Developing States," *International Security* Vol. 23, No. 4 (Spring 1999), pp. 119–147; and Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton NJ: Princeton University press 2010).

Footnote 216: The "Technology Quarterly" report of the magazine *The Economist* explored this very topic in early 2022 with a series of articles that discussed how more accurate sensors and more powerful data analytics will lead to an era of transparency. See "Like Smartphones, but Lethal: Hide and seek War among the sensors;" "All the Targets, All the Time: Synthetic-aperture radar;" "See-through seas? Finding submarines is likely to get easier;" "Fierce contests Deception and destruction can still blind the enemy;" "Lots of signal, lots of noise Where to process data, and how to add them up" *The Economist* (January 29th, 2022), https://www.economist.com/technology-quarterly/2022/01/29/the-technology-of-seeing-and-shooting-your-enemies. News from the first two months of the 2022 War in Ukraine gives credence to the interpretation of an age of increasing transparency in the battlefield. See Warren

P. Strobel and Robert Wall, "Ukraine War Puts Spy Satellites for Hire in the Spotlight," *The Wall Street Journal* (March 1, 2022), https://www.wsj.com/articles/ukraine-war-puts-spy-satellites-for-hire-in-the-spotlight-11651410002?reflink=desktopwebshare_permalink. The debate on battlefield transparency, however, has so far implied that this revolution will impact all countries equally, paying scant attention to asymmetries in sensor and processing capabilities, and to the inevitable attempt to employ counter-tactics and counter-measures – which has driven the hider-finder competition in the past 70 years (and more generally, the history of military innovations and counter-innovations). These two aspects suggest that the hider-finder competition will not disappear – it might just become even more unforgiving. For instance, journalistic accounts about the early phase of the 2022 War in Ukraine war reported how "The Russian attempt to take Kyiv was defeated by a combination of factors including geography, the attackers' blundering, Ukrainian ingenuity and modern arms — as well as smartphones: used for the first time in military history as weapons powerful in their own way as rockets and artillery. Moscow's forces were thwarted, too, by pieces of foam mat — the Ukrainians call them karemats — costing as little as £1.50. The mats prevent Russian thermal imaging drones from detecting human heat. 'We held the karemats over our head,' said [Aleksander] Konoko [a battalion commander], explaining how his men moved stealthily in tiny groups at night. In that way soldiers armed with anti-tank weapons supplied by the US, Britain and others could sneak up on the Russians, fire their deadly and accurate missiles and then slip away." See Tim Judah, "How Kyiv was saved by Ukrainian ingenuity as well as Russian blunders, *The Financial Times* (April 10, 2022), https://www.ft.com/content/e87fdc60-0d5e-4d39-93c6-7cfd22f770e8.