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Automation in air warfare: lessons for Artificial Intelligence today

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Popular discussions regarding the application of Artificial Intelligence (AI) to military aviation frequently adhere to the standard "killer robot" trope. While images of a Terminator-like, terrorist-hunting drone may be useful for capturing our attention or igniting a philosophical debate about AI, more often they are an unfortunate distraction. By focusing exclusively on the AI *in* the drone, we tend to overlook the automation *of* the drone. There is value in looking beyond the specific AI-tools and instead focusing attention on the human decisions that determined what functions of the drone needed to be automated and why. This chapter therefore attempts to reframe and elevate today's conversations about AI by invoking the rich, socio-technical history of automation and providing an example of this alternative perspective. Specifically, reviewing the automation of air-to-air combat post-World War II reveals how different groups of operators, engineers, and their respective organizations developed and then responded to their newly-automated tools.

The previous two chapters made three main abstract or theoretical claims pertinent to this discussion. First, that technological progress triggers an increasing demand for complements. Next, that technological change often demands organizational change and a reallocation of tasks between human and machines. And, last but not least, that new technologies and organizational changes raise different psychological, sociological, and political reactions as the new tools and new roles emerge. The history of automation in air combat documented in this chapter illustrates these very dynamics. Ever increasing automation did not eliminate skilled pilots from the cockpit, but it did eliminate some of their historic tasks. Consequently, tasks had to be renegotiated and reallocated between the human pilots and their aircraft machines. Finally, the introduction of automation

1 The views expressed in this document are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the US Government.

generated different forms of resistance, opposition, and later acceptance withn the various costituences. Knowing and understanding this history is important because it can aid us today as we struggle to develop and adapt to the next generation of automation powered by the latest AI algorithms.

The three myths of automation

Developing novel technologies in the hope of automating once-burdensome human tasks is not a new phenomenon. Nonetheless, we do not have a stellar record of correctly anticipating the challenges that might accompany the automation. In his historical survey of various autonomous technologies spanning sub-surface, terrestrial, aviation, and space applications, David Mindell, a professor at the Massachusetts Institute of Technology (MIT), identified three pernicious myths of autonomy that have frequently distorted our understanding of automation's effects on society. The first, the *myth of linear progress*, reflects the popular belief that automation follows a natural, deterministic trajectory, whereby our machines steadily transition from requiring direct human involvement to the intermediary of remote human presence before finally becoming fully autonomous robots. Meanwhile, the *myth of replacement* underscores the presumption that the purpose of automation is simply to mechanize existing human tasks. Finally, the *myth of full autonomy* captures the utopian idea that robots can operate entirely on their own even after they are released into the messy, complex human world outside a laboratory.[2] A cursory review of the popular literature touting future AI-fueled automation, be it autonomous passenger vehicles operating on city streets or armed, expendable drones swarming a battlefield, illustrates how these three myths continue to shape our expectations.[3]

To move beyond these myths of autonomy, we must cultivate a rich understanding of the dynamic relationship that exists between humans, their tasks, and their equipment. These three components never operate in isolation, and they must therefore be studied as a whole as part of a *cognitive enthnography* – a "system of person-in-interaction-with technology".[4] Applying this analytic approach to the development of US Air Force fighter aircraft and their associated automated fire control technologies yields valuable insights for today.

2 D.A. Mindell, *Our robots, ourselves: robotics and the myths of autonomy,* New York, Viking, 2015, pp.8-10.

3 J.M. Lutin, "Not if, but when: autonomous driving and the future of transit", *Journal of Public Transportation*, Vol.21, No.1, 2018, pp.92-103; P. Scharre, "How swarming will change warfare", *Bulletin of the Atomic Scientists*, Vol.74, No.6, 2018, pp.385-389.

4 E. Hutchins, *Cognition in the wild,* Cambridge, MIT Press, 1995, p.155. See also T.B. Sheridan, *Telerobotics, automation, and human supervisory control,* Cambridge, MIT Press, 1992.

Patterns of automation in US Air Force fighter aviation

The United States Air Force (USAF) staked its future on advanced technology and automation even before its founding as a separate service in 1947. Exiting World War II, the then-Army Air Forces chartered its landmark, multivolume *Toward New Horizons* study to explore the relationship "between science and aerial warfare".[5] This early fascination with technology played a significant role in the fledgling service's later development, yielding what Carl Builder termed an "Icarus Syndrome".[6] Still, as one recent scholar noted, unlike the other US military services, the USAF is necessarily dependent on advanced technology to justify its very existence – humans do not fly without technology.[7]

From the F-86 Sabre to the F-4 Phantom to the F-15 Eagle and beyond, historic fighter pilot tasks have succumbed to ever-expanding aircraft automation. But the automation did not come conflict-free. Battles over who decided what tasks to automate and how to automate them were common, especially within the hyper-masculine community of jet fighter pilots. Over the last fifty years, those who flew and those who built the newest fighter aircraft have wrestled with a fundamental question: what is the goal of the automation? Is it to *eliminate* human skill in the cockpit or to *free* it to accomplish other tasks?

The F-86E Sabre

The F-86E Sabre was one of the first USAF fighter aircraft to feature a small radar to aid the pilot with aerial gunnery. Determining the range to an enemy target had always been a challenging prerequisite to a successful gunshot. Prior fighter pilots relied on a manually actuated, mechanical range estimator in their gunsight to guide their aim.[8] The process was cumbersome and pilots admitted it was especially challenging "trying to do everything at once" during a frenetic dogfight.[9] One engineer labeled the problem of range estimation

5 T. von Karman, "Science, the key to air supremacy: a report to General of the Army H.H. Arnold", in *Towards New Horizons*, Vol.1, Headquarters, Army Air Forces, 1946.

6 C.H. Builder, *The Icarus syndrome: the role of air power theory in the evolution and fate of the US Air Force,* New Brunswick, Transaction Publishers, 1994.

7 J.W. Donnithorne, *Four guardians: a principled agent view of American civil-military relations,* Johns Hopkins University Press, Baltimore, 2018, chapter 5. See also T.P. Schultz, *The problem with pilots,* Johns Hopkins University Press, Baltimore, 2018.

8 *Harmonization and firing techniques for fighter aircraft*, Armament Laboratory, Air Research and Development Command, March 1952, National Museum of the USAF (NMUSAF), pp.31-37.

9 D.K. Evans, *Sabre jets over Korea: a firsthand account,* Blue Ridge Summit, Tab Books, 1984, p.85.

"the bugaboo of aerial gunnery".[10]

The USAF's new A-1CM gunsight, and its accompanying small APG-30 radar, promised to solve the problem. Forecast in *Toward New Horizons* and designed by a team at MIT, the new radar-equipped gunsight was hailed as a major innovation.[11] The *New York Times* boasted the new "secret radar sight [...] does everything but fly the plane".[12] USAF publications similarly extolled the virtues of a "gunsight almost completely automatic in its operation", proclaiming the A-1CM "superior to any other fixed Gun Fire Control system".[13] No longer would a pilot need to spend countless hours practicing his dogfighting skills and learning how to close with his adversary. Instead, now aided by the automated A-1CM, fighter pilots would be able to score hits "with extreme accuracy at hitherto impossible ranges".[14]

The automated gunsight heralded a new division of cockpit tasks, at least according to the engineers. The human obviously would still pilot the aircraft, but when it came to shooting down a foe, the gunsight would be in charge; the pilot would simply maneuver his aircraft to place the gunsight's automatically calculated aiming pipper over the target and then squeeze the trigger.[15] Reflecting this arrangement, the pilot was provided with only minimal controls for the gunsight and its accompanying equipment. In the case of the radar, that included only a single power switch, a single light bulb that illuminated whenever the radar achieved a radar lock, and a single button on the control stick to temporarily break the radar lock.[16] Engineers scolded stubborn fighter pilots who didn't adhere to the defined relationship, informing those pilots that "snap decision corrections or judging will

10 F.H. Greene, Jr., to Commanding General, Continental Air Command, 31 January 1950, Charles Stark Draper Lab-Historical Collection (CSDL-HC).

11 L.A. DuBridge *et al.*, "Radar and communications: a report for the AAF Scientific Advisory Group*", Toward New Horizons*, Vol.11, p.22.

12 "New radar sight guides jets' guns", *New York Times*, 3 April 1950.

13 *A-1 series (gun-bomb-rocket) sight,* Continental Air Command Manual 50-11, Vol.2, No.2, Mitchell AFB, Headquarters, Continental Air Command, 1952, Air Force Historical Research Agency (AFHRA); *Operational suitability test of the A-1CM gun-bomb-rocket sight (F-84E Phase with AN/APG-30 Radar Ranging),* Project APG/ADB/8-A, Eglin AFB, Air Proving Ground Command, 18 December 1950, Defense Technical Information Center (DTIC), p.2.

14 *Harmonization and firing techniques for fighter aircraft*, p.1; *Operational suitability test of the A-1CM gun-bomb-rocket sight*, p.10. Because fighter aviation in the USAF was closed to women until the early 1990s, male-specific pronouns are used in this text.

15 I.A. Getting, "Conference on fighter fire control", Ad Hoc Group on Airborne Fire Control Systems for Fighter Aircraft, Cambridge, MIT Instrumentation Laboratory, 16 January 1953, DTIC, p.I-5.

16 *Harmonization and firing techniques for fighter aircraft*, pp.42-44; *T.O.1F-86A-1*, F-86A Aircraft, Flight Handbook, 30 August 1957, NMUSAF, sect.4, pp.20-23.

not improve results obtainable with the A-1C sight".[17]

The fighter pilots dueling in the skies over the Yalu River during the Korean War had a different perspective. For them, the new electronic gadgetry had not changed dogfighting nor reduced their human role within it. "It's still a matter of seeing first and trying to get on the other's tail or shaking him off yours", one explained.[18] Another preached, "[a]pproximately 90 percent of your air-to-air combat is positioning. [...] If your [*sic*] not in position your [*sic*] not going to get a kill".[19] By their estimation, the A-1CM at best only helped with the last 10 percent of the mission, and many thought the new gunsight actually degraded their ability to successfully accomplish the other 90 percent. Within a year, scarcely half of the A-1CM gunsights in Korea still functioned.[20]

The automatic gunsight unsettled the fighter pilot ranks for another reason. Since WWI, the universal measure of a fighter pilot's skill was his record in air combat, with five aerial kills earning the victor the title of *ace*.[21] But if downing a foe was now to be largely automated, what role was then left for the human? The pilots' concerns were reflected in a cartoon published in the 1951 edition of their professional journal, *Fighter Gunnery*. In it, a bloodied fighter pilot lies crushed beneath an enormous box labeled "Gun Sight".[22] One pilot-friendly commentator explained after war's end, "In our enthusiasm for the electronic gadgets which take the thrill out of aerial gunnery and grab the controls from the pilot, we are inclined to forget that science has yet to produce leadership by remote control".[23]

Little more than a year after the A-1CM was thrust into the violent skies over Korea, scores of F-86 pilots were ready to forsake the one tool explicitly designed to make them more lethal. In late summer 1952, 14 Korean War aces approached the Chief of Staff of the Air Force (CSAF) and beseeched him to suspend all development of radar-assisted gunsights. The aces were convinced the "intricate, highly complicated electronic equipment" did not work.[24] One of them had reportedly once remarked he was better

17 E.M. Olsen, "Evaluation of Results of the 1950 USAF gunnery meet", 13 April 1950, CSDL-HC.

18 Evans, *Sabre jets over Korea: a firsthand account*, p.181.

19 Col. R.N. Baker, *Report on F-86 operations in Korea*, 1 April 1953, AFHRA, p.11.

20 Col. F.S. Gabreski, *(End of Tour) Report by Colonel Francis S. Gabreski*, 8 July 1952, AFHRA, p.6; *FEAF Report on the Korean War,* Vol.2, 1954, AFHRA, p.11.

21 R.A. Wohl, *A passion for wings: aviation and the Western imagination, 1908-1918,* New Haven, Yale University Press, 1994, pp.203, 304, n.2.

22 "Birth of a gunsight", *Fighter Gunnery*, Vol.1, No.3, 1951, pp.8-9.

23 H.C. Stuart, "Salute to combat leaders", *Air Force,* Vol.35, No.9, September 1952, p.24.

24 *Accelerated comparison test of the K-14 sight and J-2 fire control system in the F-86E for fighter to fighter combat*, Project APG/ADB/59-A, Eglin AFB, Air Proving Ground Command, 26 September 1952, DTIC, Inclosure 1, pp.5-6;

off using "a piece of chewing gum in the windshield".[25] Summarizing their rationale, the CSAF agreed it might be "most unwise to burden our fighters with 205 extra pounds of gunsight complexity and unreliability".[26] Within weeks, the CSAF ordered an immediate test comparing the performance of the new radar-ranged gunsights with that of their older, manually-ranged cousins. He invited several of the same 14 aces, ranging from lieutenants to colonels, to participate in the test.[27]

The aces were a powerful constituency, but they were not the only one. By the time the CSAF's test kicked off in September 1952, other fighter pilots still flying in Korea had already begun to forge a more collaborative relationship with their gunsight. This fresh crop of pilots opted to discard the strict division of labor originally articulated by the engineers. The pilots began to seek out and study technical manuals that detailed the assumptions built into the gunsight.[28] They scavenged parts and constructed a simulator to further their understanding of the gunsight's operation.[29] And they cultivated collaborative relationships with the engineers, culminating in an innovative radar range-limiter that offered the pilots more control over their automated equipment.[30] Simultaneously, the USAF launched a massive effort to repair and rehabilitate the malfunctioning gunsights.[31] Based on this budding partnership, the pilots still fighting in Korea offered a different assessment, writing the CSAF that "removing the A1CM gunsight" would be a step "made backward instead of forward".[32]

Ultimately, the USAF elected to continue developing its radar-ranged, automated fire

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FEAF Report on the Korean War, pp.11-12.

25 Quoted in K.P. Werrell, *Sabres over MiG Alley: the F-86 and the battle for air superiority in Korea,* Annapolis, Naval Institute Press, 2005, p.30.

26 Quoted in CG FEAF to CG AF FIVE, "Personal from Smart to Barcus", *History of the 5th Air Force*, Vol.3, 1952, AFHRA.

27 *Accelerated comparison test*, pp.1-2, Inclosure 1, pp.5-6; *FEAF Report on the Korean War,* pp.11-12.

28 *History of the 4th fighter-interceptor wing, Oct. 1951*, AFHRA, chapter 6; *History of the 51st fighter interceptor wing, Feb 1952,* AFHRA, chap.2; *FEAF Report on the Korean War,* pp.11-12.

29 "Radar and gunsight shop", *History of the 4th fighter-interceptor wing, Jul-Dec 1952,* AFHRA, pp.70-71; "Maintenance, supply, communications, and armament history", *History of the 4th fighter-interceptor group*, *Jul 1952*, AFHRA.

30 J.L. Jenkins, "Some notes on the behavior of computing gunsights", *Fighter Weapons Newsletter*, No.1, February 1956, Muir S. Fairchild Research Information Center (MSFRIC), pp.51-53; *FEAF Report on the Korean War*, p.11; *History of the 4th fighter-interceptor wing, Jul-Dec 1952*, p.70; *History of the 6400th air depot wing*, *Feb-Jun 1952,* Vol.1, AFHRA, pp.230-31.

31 *FEAF Report on the Korean War*, p.11; *History of the 6400th air depot wing, Feb-Jun 1952*, pp.114, 261.

32 Brig. Gen. D.D. Hale, USAF, to Commanding General, Far East Air Forces, "A1CM Gunsight", 17 September 1952, in *History of the 5th Air Force, Jul-Dec 1952*, AFHRA, pp.2-4.

control systems, confident that the more advanced systems would be needed in future conflicts. The results of the CSAF-directed comparison test offered hope, concluding that, despite what the aces had said, using a radar-ranged sight doubled the probability of achieving a kill.[33] Still, the USAF wrestled with the realization that aiming and squeezing the trigger *was* only 10 percent of the final solution, and its automated A-1CM could do little to assist the pilot with the other 90 percent. But what if there were even more advanced weapons that didn't rely on a pilot's sharp eyesight, deft maneuvering, and steady aim? Even better, what if these new weapons could actually maneuver in mid-air, on their own, to chase down a wily foe?

The F-4C Phantom II

The USAF's next generation fighter, the F-4C Phantom II, embodied that vision of autonomous weaponry. Originally built for the US Navy but later acquired by the USAF, the F-4C did not even come equipped with an internal gun to shoot down the enemy; it relied solely on a mix of heat-seeking and radar-guided missiles.[34] The engineers were ecstatic. By decoupling the performance of the weapon from that of the aircraft, the new missiles provided unprecedented design flexibility.[35] The new guided missiles could travel higher, further, and faster. Plus, they would be "powerful enough to insure [*sic*] a kill".[36] The pilots were enthralled, too. Describing the allure of the heat-seeking Sidewinder, a USAF pilot remarked in 1958, "the elusive MiG flying 10,000 to 15,000 feet above us in Korea would be real meat for the GAR-8 [Sidewinder]. We might have to revise our standards for qualifying as an ACE in future conflicts".[37]

Almost a decade after that ringing endorsement, and nearly two years after the United States initiated its prolonged bombing of North Vietnam, a group of Phantoms launched from their base in Thailand on a special mission. Led by their famed commander, Colonel Robin Olds, the F-4 fighters successfully goaded 14 North Vietnamese MiG-21s into the air on 2 January 1967. In the ensuing melee, Olds launched two radar-guided Sparrow

33 *Accelerated comparison test*, pp.1-2.

34 *F-4C system package program,* 62 ASZM-52, Air Force Systems Command, rev. September 1963, Air Force Materiel Command/History Office (AFMC/HO), sect.6 and sect.12, p.8; *History of the Tactical Air Command, Jul-Dec 1961*, Vol.1, AFHRA, pp.194-202.

35 G.E. Bugos, *Engineering the F-4 Phantom II: parts into systems,* Annapolis, Naval Institute Press, 1996, pp.27-28.

36 *Air-to-air guided missiles,* Lecture Manuscript, R-49, Tyndall AFB, Air Tactical School, Air University, 16 April 1948, AFHRA, pp.1-2.

37 Capt. R.M. Thor, USAF, "GAR-8", *Fighter Weapons Newsletter,* June 1958, MSFRIC, p.30.

missiles to no avail. Then he launched a Sidewinder, but it too careened off-course shortly after launch. After some hard maneuvering, Olds spied the glint of yet another MiG-21 in the distance. He zoomed high above the horizon, did a barrel roll around the unsuspecting foe, and dove toward its six o'clock. From approximately 4,500 feet away and 15 degrees off the bandit's tail, he fired his fourth missile – another Sidewinder.[38] According to his post-mission report, "Suddenly the MiG-21 erupted in a brilliant flash of orange flame".[39]

All told, Olds and his teammates attempted to fire 31 missiles that day: 19 radar-guided and 12 heat-seeking.[40] For that, they downed a total of seven enemy MiG-21s, and their mission – Operation BOLO – became the USAF's greatest aerial victory of the Vietnam War. The missiles' lackluster performance that day was not atypical, however. It was above average; Olds's team had spent weeks "peaking" their aircraft and weapons for the big mission.[41] Indeed, by the end of the Vietnam War, less than one third of the USAF's guided missiles launched against enemy fighters successfully found their target.[42] The woeful missiles, and the Phantom's singular reliance on them, became a significant concern for the fighter pilots during Vietnam. Analogizing their fate, the pilots explained they had been given "a ten-foot spear" and then locked in a "five-by-five closet" with an enemy armed with "a knife".[43] As in Korea before, the pilots felt victimized by the Pentagon's appetite for complex, automated technologies.[44]

There were other challenges, too, that accompanied the new autonomous weapons. Ever

38 Brig. Gen. R. Olds, USAF, "Briefing to the staff of project CORONA HARVEST on operation BOLO", 29 September 1969, AFHRA; Lt. Col. C.H. Asay, USAF *et al.*, *History of operations BOLO*, in *History of the 8th tactical fighter wing, Jan-Jun 1967*, Vol.2, AFHRA; Maj. G.Y.W. Ow, USAF, *Mission Bolo, 2 January 1967, F-4C vs MiG 21's,* Working Paper 67/3, Directorate, Tactical Air Analysis Center, Headquarters, 7th Air Force, 13 February 1967, AFHRA; J.S. Attinello, *Air-to-air encounters in Southeast Asia: account of F-4 and F-8 events prior to 1 March 1967*, Report R-123, Vol.1, Institute for Defense Analyses, Systems Evaluation Division, October 1967, DTIC, pp.415-46.

39 Quoted in Asay *et al.*, *History of Operations BOLO*, p.41.

40 *Ibid.*, pp.17-21. Maj. Ow recorded 20 radar-guided missiles attempted in *Mission Bolo,* 3.

41 Olds, "Briefing to the staff of Project CORONA HARVEST on operation BOLO", pp.12-14; Asay *et al.*, *History of operations BOLO*, Annex F.

42 M.L. Michel III, *Clashes: air combat over North Vietnam, 1965-1972,* Annapolis, Naval Institute Press, 1997, pp.286-87.

43 Brig. Gen. J.W. Cook, USAFR (ret.), *Once a fighter pilot...* New York, McGraw-Hill, 2002, p.210; Maj. Gen. F.C. Blesse, USAF, Corona Ace Oral History Interview, by Lt. Col. G.F. Nelson, USAF, 14 February 1977, AFHRA, pp.59-60.

44 For a sampling, see Maj. Gen. J.J. Burns, USAF, Oral History Interview, by J. Neufeld, 22 March 1973, AFHRA, pp.3, 9, 14-18; Maj. Gen. R.C. Catledge, USAF (ret.), Oral History Interview, by 1Lt. W.D. Perry, USAF, 30 September 1987 and 9 December 1987, AFHRA, pp.30-32; Blesse, Corona Ace Oral History Interview, pp.59-61.

since Roland Garros opted in 1915 to risk shooting off his own propeller rather than lug around a second person, fighter pilots had reveled in the independence and autonomy of a single seat fighter.[45] The Phantom upended that proud history. The increased automation of the F-4C and its weapons required a second crewmember be reinserted into the cockpit.[46] The front-seater according to the flight manual was the Aircraft Commander; he focused on flying the powerful fighter. It was the back-seater's responsibility to operate the aircraft's complex radar; the flight manual referred to him as the Pilot Systems Operator, but more often he was simply called the GIB – the Guy-In-Back.[47]

Neither individual wanted to share the cockpit with the other. Many front-seaters had already flown single-seat fighters, and the sudden intrusion of a young lieutenant GIB telling him where or how to fly was perceived by some as a threat to their "manhood".[48] The front-seaters felt they "didn't need anybody back there", one GIB recalled.[49] The back-seaters for the most part reciprocated the sentiment. For several years, the USAF GIBs were fully trained pilots usually plucked fresh from flight school.[50] "We had soloed [...] We had flown formation; we had done all sorts of things [...] We felt like young tigers and now we were going to be put in the back seat with another guy", one GIB lamented.[51] Describing their plight, another acknowledged, "[i]t was demoralizing".[52]

Despite the tension, teamwork was essential. The pilot in the front seat might have had a large radar screen mounted prominently at eye level, but he had zero control over its

45 Wohl, *Passion for wings*, pp.203-10; J. Werner, *Knight of Germany: Oswald Boelcke, German Ace*, translated by C.W. Sykes, Philadelphia, Casemate, 2009, p.135; J. Salter, *The hunters,* New York, Vintage, 1956, p.193.

46 "The advantage is here: why the Phantom II has a two man crew", *Air Force & Space Digest,* June 1962; Bugos, *Engineering the F-4*, pp.26-27, 98.

47 *T.O. 1F-4C-1*, USAF Series F-4C and F-4D Aircraft, Flight Manual, 15 February 1979, NMUSAF; *F-4 Aircrew operational procedures*, TACM 55-4, Vol.1, PACAFM 55-5, Vol.1, USAFEM 55-4, Vol.1, Langley AFB, Headquarters, Tactical Air Command, May 1968, AFHRA, pp.1, 29; Col. H.J. Hill, USAF (ret.), Oral History Interview, by J.C. Hasdorff, 12 July 1991, AFHRA, pp.20-21.

48 Gen. L.D. Welch, USAF (ret.), interview by author, 1 October 2013; A.R. Scholin, "New phlyers for the Phantom", *Air Force & Space Digest,* January 1968, pp.46-48; *History of the Tactical Air Command, Jul-Dec 1962*, Vol.1, AFHRA, pp.182-83.

49 Capt. J.L. Hendrickson, USAF, Oral History Interview, by Maj. L.R. Officer, USAF, and H.N. Ahmann, 31 January 1973, AFHRA, pp.61-62.

50 Lt. Gen. J.J. Burns, USAF (ret.), Oral History Interview, by H.N. Ahmann, 5-8 June 1984, AFHRA, pp.215-17; Col. C.R. Anderegg, USAF (ret.), *Sierra hotel: flying Air Force fighters in the decade after Vietnam,* Washington, DC, Air Force History and Museums Program, 2001, pp.40-41; Hendrickson, Oral History Interview, p.99; Lt. Gen. J.T. Robbins, USAF (ret.), Oral History Interview, by J.C. Hasdorff, 24-25 July 1984, AFHRA, pp.105-8.

51 Hill, Oral History Interview, pp.21-22.

52 Brig. Gen. F.K. Everest, USAF (ret.), Oral History Interview, by H.N. Ahmann, 23 September 1988, AFHRA, p.13.

operation. Only the GIB could turn on the radar, and only he could configure its operating mode and adjust its search pattern. Thus, it was the GIB who was responsible for staring at a screen full of "fuzzy blips" and distinguishing between real targets and false ones. When he found a real target, it was the GIB alone who could manually lock on to it. And without that all-important, properly-configured radar lock, the four radar-guided Sparrow missiles slung beneath the Phantom's belly were mere ballast.[53]

When the missiles did work, either radar-guided or heat-seeking, there was still ample opportunity for friction. As mentioned above, aerial victories had always been the ultimate scorecard for fighter pilots, and achieving a kill was recognized as a very intimate, personal affair that relied on individual pilot's cunning and skill. But in the Phantom, who deserved the credit for a kill? The front-seater, for maneuvering the aircraft and pushing the pickle-button to fire the missile? The back-seater, for getting the radar lock? Or the missile, for successfully steering itself toward the target? Automation had entangled the different human and machine contributions and it became impossible to disaggregate them. It took a CSAF decision in spring 1972, more than five years after Olds's famed sortie, to resolve the squabble.[54] But the USAF's decision to recognize both front-seater and GIB each with a full victory credit for every kill was not universally praised. One pilot remarked, "I think it confused the hell out of things".[55]

In fighter aircraft prior to the F-4, such as the F-86, the task of flying the plane was roughly synonymous with employing it in battle – do the first well and the second naturally followed. The complex human-machine relationships embedded within the Phantom altered this dynamic. Pilots became "systems operators".[56] The automation in the Phantom had changed what a fighter pilot did in the air, who he worked with, and how he accomplished his mission. But it had not eliminated human skill – the human operators still played an essential role. A photograph that accompanied the *New York Times* story detailing the USAF's first aerial victory in Vietnam subtly captured the evolving relationship. In the

53 *F-4 aircrew operational procedures*, 29; *F-4C air combat tactics*, Course No.111509F, Phase Manual, MacDill AFB, July 1966, in *History of the 15th tactical fighter wing, Jul-Dec 1966*, Vol.2, AFHRA, pp.18, 21; *T.O. 1F-4C-34-1-1*, USAF Series F-4C Aircraft, Aircrew Weapons Delivery Manual (Nonnuclear), 1 February 1976, NMUSAF, sect.1, p.30; *8th tactical fighter wing tactical doctrine*, March 1967, in *History of the 8th Tactical Fighter Wing, Jan-Jun 1967*, Vol. 2, pp.81-84.

54 R.F. Futrell *et al.*, *Aces and aerial victories: the United States Air Force in Southeast Asia, 1965-1973,* Washington, DC, Office of Air Force History, 1976, p.vi; Col. C.R. Anderegg, USAF (ret.), interview by author, 2 October 2013.

55 Burns, Oral History Interview, June 5-8, 1984, p.219.

56 Welch, interview. See also Olds's similar assessment in "'Ace' fighter wing commanded by 'Aces'", *USAF News Release*, November 1966, AFHRA.

past, a victorious fighter pilot was usually photographed climbing out from his cockpit, alone; now the victory photo was a team shot that included the front-seat pilot, his GIB, and the missile.[57]

The F-15 Eagle

The F-15 Eagle, which took flight in the mid-1970s, was designed to be the "Fighter Pilot's Fighter".[58] With its sleek lines, large bubble canopy, and an internal gun, the Eagle was more reminiscent of the F-86 Sabre than the F-4 Phantom. The USAF longed for the same 10:1 kill ratios that had marked the former's reign of the skies over Korea, too.[59] But the Eagle also incorporated a large, powerful radar and guided missile ordnance, the same equipment that had necessitated a second seat in the Phantom. Nevertheless, fighter pilots were eager to discard the ignominy of flying with a GIB, and consequently the F-15A Eagle would not come with a second seat. In the words of an early F-15 concept paper, "careful attention to automation design" would therefore be necessary.[60]

Some of the automation in the F-15 focused on reducing the pilot's tasks associated with flying the massive, twin-engine fighter jet. For example, an air data computer automatically calibrated the position of the hydraulically actuated, variable-geometry engine inlets based on air temperature and airspeed to ensure proper airflow to the engines.[61] The classic hydromechanical flight control system received an upgrade, too, now boosted by a progenitor of the fly-by-wire control systems used on later fighter aircraft.[62] Not all appreciated the new systems, though. For some prospective pilots, the flight control augmentation system sounded like "black magic" or "something out of *Star Trek"* and they

57 "Pilots describe downing of MIG's", *New York Times,* 12 July 1965.

58 Capt R.J. Hoag, USAF, "Superfighter", *Fighter Weapons Review*, Summer 1974, MSFRIC, p.21; "F-15: a fighter pilot's fighter", McDonnell Douglas advertisement in *Air Force*, August 1971 and October 1971.

59 Gen. J.C. Meyer, USAF, "Air Superiority into the 1980s", *Air Force*, August 1971, p.43.

60 Lt. Col. O'Donohue, USAF, "Development concept paper: new Air Force tactical counter-air fighter (F-X)", 15 September 1968, in *History of the F-15 Eagle*, Vol.2, AFHRA, p.7; D.M. Gillespie, "Mission emphasis and the determination of needs for new weapon systems", Ph.D. dissertation, MIT, 2009, pp.224-25; Brig. Gen. R. Olds, USAF, "The lessons of Clobber College", *Grumman Horizons* 8, No.1, 1968, pp.18-22; Capt. R.S. Ritchie, USAF, Oral History Interview, by Maj. L.R. Officer, USAF, and H.N. Ahmann, 11 and 30 October 1972, AFHRA, p.29.

61 *F-15 Eagle,* Report H446, McDonnell Aircraft Company, 15 July 1969, AFMC/HO, pp.1-2; *USAF F-15 Fighter summary,* Wright-Patterson AFB, Deputy for F-15/JEPO, Headquarters for ASD, 1 May 1971, AFMC/HO, p.12.

62 *T.O. 1F-15A-1*, F-15A/B/C/D Aircraft, Flight Manual, 15 January 1984, NMUSAF, sect.1, p.30; *F-15 Eagle*, p.7; *USAF F-15 Fighter Summary*, p.7.

expressed their concern, "What happens when some berserk electron decides to go on a rampage?"[63] Still, most were enthusiastic. General William Momyer, a three-war fighter pilot veteran and then-commander of the USAF's Tactical Air Command, declared "the F-15 as having 'more potential than a pilot can psychologically take'".[64] Another said it was like "going from an F-150 pickup truck to a Corvette".[65]

The greatest advances in automation, however, centered on the pilot's interaction with the Eagle's radar and weapons. In the Phantom, a human GIB was needed to operate the complex radar. In the Eagle, the radar was specially designed for "one-man operation". The tasks of adjusting the gain and distinguishing between real and false targets was now assigned to the radar itself through new waveforms and automated signal processing.[66] The pilot's interactions with his aircraft weapons systems were also transformed. Instead of relying on a human-GIB intermediary, the F-15 pilot now communicated directly with his aircraft weapons systems using a "very intelligent" 48.5-pound box mounted underneath his feet – the aircraft's central computer.[67]

No longer would the pilot need to verbalize his desired radar or weapons mode changes and wait for the GIB to respond. Instead, he used his HOTAS (Hands-On-Throttles-And-Stick) functions, all monitored and processed by the central computer, to do it "himself". The maze of HOTAS functionality available with the eight separate controls mounted on the throttles and the additional five buttons affixed to the control stick, all of which needed to be actuated in separate, precise sequences, could be daunting. "It is true the throttles are designed for busy hands", one of the USAF's chief F-15 test pilots acknowledged. But, he continued, "the F-15 cockpit design and pilot procedures are simple and uncomplicated and require no more than average physical dexterity and common sense".[68] Pilots abruptly realized that operating the HOTAS correctly was a perishable skill that demanded constant honing. It became known as "playing the piccolo".[69] Mastering its use, the F-15 pilots were

63 Hoag, "Superfighter", pp.22-23.

64 Quoted in "F-15 Rolls Out at St. Louis", *Flight international*, 6 July 1972, p.11.

65 Quoted in Anderegg, *Sierra hotel,* p.150.

66 *Eyes of the eagle: the Hughes APG-63 Radar,* Culver City, Radar Avionics-Aerospace Group, Hughes Aircraft Company, 1976, NMUSAF, p.2; *F-15 avionics and armament mission requirements analysis: report of the ad hoc committee*, Andrews AFB, MD, Headquarters, Air Force Systems Command, 17 August 1970, AFMC/HO, pp.125-26; Hoag, "Superfighter", p.22.

67 Hoag, "Superfighter", pp.26-27; Anderegg, *Sierra hotel*, p.154; Maj. W.G. Flood, USAF, and Maj. J.S. Rodero, USAF, *F-15 Initial operational test and evaluation - air-to-air (Annex A),* TAC Project 71C-223W, Final Report (Interim), Nellis AFB, USAF Tactical Fighter Weapons Center, April 1975, AFMC/HO, p. A:2; *T.O. 1F-15A-1*, sect.1, p.76.

68 Hoag, "Superfighter", pp.22, 25.

69 Anderegg, *Sierra hotel*, p.157.

told, would give them "a significant advantage in the dogfight scenario".[70]

The Eagle might have been custom-built for dogfights, but rapid advances in adversary weapons soon rendered the close-quarters engagement especially lethal for all involved. An F-15 would still likely get the kill, but it was just as likely to be killed in the process.[71] The impressive automation of the Eagle's radar and weapons systems, coupled with continued improvements in US air-to-air missile performance, allowed the pilots to adjust their tactics. Dogfighting promptly gave way to "sorting". Before the transition, targeting enemy aircraft at long-range was largely driven by chance, often resulting in some targets being shot multiple times by different F-15s while other targets emerged from the missile volley unscathed. To avoid this outcome, an F-15 flight leader could "sort" his accompanying fighters to the different enemy targets. However, the tactic required all aircraft in the formation to possess a common radar picture so that each individual pilot could understand and then execute the communicated targeting scheme.[72] Even with two humans in each cockpit, this wasn't possible in the Phantom. But with the Eagle's advanced, automated radar and HOTAS, it suddenly became viable, even if neither function was originally designed with sorting in mind.[73]

The resulting transition in tactics shattered the dogma that since the end of WWI had governed the types of fighter formations flown and the individual responsibilities within those formations. In the past, the formation leader focused almost exclusively on offensive employment while his wingman defended him.[74] Now, with "sorting" all the fighters in a formation had an acknowledged offensive role and all were mutually responsible for ensuring the formation's survival and success.[75]

Automation had changed fighter aviation again. As improvements in aircraft design,

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70 *F-15 Eagle Fact Sheet,* 73-2, Washington, DC, Secretary of the Air Force, Office of Information, Internal Information Division, February 1973, AFMC/HO, p.2.

71 Maj. Gen. F.C. Blesse, USAF (ret.), "The changing world of air combat", *Air Force*, October 1977, p.34; "No-win war at Dogbone Lake", *US News & World Report*, 9 January 1978, pp.56-57.

72 Anderegg, *Sierra hotel*, p.160; Col. T. Sokol, USAF (ret.), interview by author, 4 August 2013; Col. C.R. Anderegg, USAF (ret.), interview by author, 2 October 2013.

73 Anderegg, *Sierra hotel*, p.156. Maj. Gen. J. Cliver, USAF (ret.), interview by author, 3 August 2012; Sokol, interview.

74 J. Stocker, "A wing man has to have eyes in the back of his head", *Air Force*, March 1955, p.32; *4th Fighter-interceptor group tactical doctrine*, 22 July 1951, in *History of the 4th fighter-interceptor group, Jul-Sep 1951,* AFHRA, p.9; Maj. Gen. E.A. Bedke, USAF (ret.), Oral History Interview, by D.G. Lamb, 25-26 January 1988, AFHRA, p.41-42; Anderegg, *Sierra hotel*, p.21; Michel, *Clashes*, pp.170-72.

75 Anderegg, *Sierra hotel*, p.163; Flood and Rodero, *F-15 Initial operational test and evaluation – air-to-air*, pp.A:25, A:85.

engines, and advanced flight controls leveled the playing field, the significance of a pilot's stick-and-rudder flying skills waned. In its place, fighter pilots had to develop a new air combat intuition that encompassed their interactions with their radar and central computer, as well as their mutually-supportive flightmates. In the Eagle, fighter pilots were transformed from being "systems operator[s]" into "information integrator[s]".[76] It wasn't the "best hands" that defined a good fighter pilot anymore, one former Phantom and Eagle pilot explained. Now it was who had the "best head".[77]

Beyond the F-15 Eagle

But what if even these human information-integration tasks could be automated? They were in the F-22 Raptor. Relying on a design philosophy known as sensor fusion, the F-22 Raptor was built to automatically gather and process information from a variety of on-board and off-board sensors and fuse it into a single, comprehensive picture of the battlespace.[78] The net result, according to industry publications, was a next-generation fighter plane that promised to "significantly reduce the pilot workload during battle conditions".[79] The pilots had other designs. Rather than merely allow the automation to simplify their tasks, the Raptor pilots instead used the automation to perform new tasks and new missions that until then had been judged nearly-suicidal.[80]

Another alternative to alleviating pilot workload would be to automate the flying itself, removing the human from the aircraft. The Predator and its later cousin, the MQ-9 Reaper, have come a long way from their inauspicious Unmanned Aerial Vehicle (UAV) beginnings. When first unveiled in the mid-1990s, the unarmed RQ-1 Predator was designed to drone along pre-programmed routes collecting intelligence. The two-person human crew was there simply to babysit the aircraft; outside of takeoffs and landings, they would intervene only if the aircraft alerted them to a problem. The first Ground Control Station (GCS) reflected this strict division of labor – just four computer monitors were deemed sufficient

76 Welch, interview.

77 Anderegg, *Sierra hotel*, p.164.

78 D.A. Fulghum and M.J. Fabey, "F-22: unseen and lethal", *Aviation Week & Space Technology*, 8 January 2007; K.W. Greeley and R.J. Schwartz, "F-22 cockpit avionics: a systems integration success story", in *Proceedings of the SPIE* 4022, Cockpit displays VII: displays for defense applications, pp.52-62; "Holding four aces: speed, stealth, agility, and revolutionary avionics", *Avionics Magazine: Special Report, Air Dominance with the F-22 Raptor*, 2002, pp.3-5.

79 R.W. Brower, "Lockheed F-22 Raptor", in C.R. Spitzer (ed.), *The Avionics Handbook*, chapter 32, New York, CRC Press, 2001, sect.5.

80 Fulghum and Fabey, "F-22".

for each crewmember to perform their limited supervisory tasks.[81]

However, once freed from the demands of "flying" their aircraft and with their "cockpits" no longer constrained by the physics of flight, the crews transformed their tasks and their roles. Furnished with an unblinking vantage over a turbulent battlefield, the crews realized they were "uniquely empowered to manipulate, coordinate, and integrate information", one researcher observed, "from an ever-expanding constellation of people and automated tools". Collaborating with a host of others spread across the world, the aircrews worked tirelessly to investigate and "identify patterns and discontinuities" that no machine algorithm could yet resolve.[82] As these tasks evolved, so did the GCS. The number of computer screens eventually doubled and occasionally whiteboards were strung along the sides of the "cockpit" to help the crews manage the information deluge.[83] The later addition of weapons to the aircraft only hastened the human crew's metamorphosis.

In the midst of these changes, the USAF adjusted the name of the aircraft from UAV to RPA (Remotely Piloted Aircraft) to emphasize the humans' role operating it.[84] Regrettably, those human contributions often went unacknowledged. The crews may not have been *physically* present over the battlefield, but they were there *virtually*, and with a closer, clearer vantage than all but a select few. Their missions were incredibly complex and deadly serious, yet the RPA crews' actions were frequently dismissed as though they were simply playing "a big video game".[85] Lost in the rhetoric was that, while the RPA pilots might not have been performing classic piloting tasks using a stick and a rudder, the fighter pilots in an F-15 or F-22 were more likely focusing on the same types of information management tasks as their RPA-brethren.

81 Lt. Col. T.M. Cullen, USAF, "The MQ-9 reaper remotely piloted aircraft: human and machines in action", Ph.D. dissertation, MIT, 2011, pp.64, 254.

82 *Ibid.*, pp.43, 168, 272, 277, 287.

83 *Ibid.,* pp.66, 96, 130, 188, 256, 258.

84 M. McCloskey, "Charting a new course: air force sees culture shift as drone mission gains momentum", *Stars and Stripes*, 27 October 2009.

85 Cited in Cullen, "MQ-9 reaper remotely piloted aircraft", p.9. See also Capt. J.O. Chapa, USAF, "Remotely piloted aircraft and war in the public relations domain", *Air & Space Power Journal,* Vol.28, No.5, October 2014, pp.29-46.

Lessons for automation today

Today's defense planners are frequently implored to "think differently" about the next conflict and the tools that will be needed to prevail. AI and autonomy frequently appear near the top of the list.[86] But too often pundits confuse the two. AI is certainly important, but how we use that AI is much more so. Today's latest AI algorithms are but a new tool that can be applied to the old problems of automation.

The history of USAF fighter aviation offers important lessons about the socio-technical challenges that frequently accompany automation. In each new fighter aircraft, additional automation was developed to alleviate traditional, burdensome pilot tasks. In the F-86, it was calculating the range to an enemy target. By the time of the F-4, a radar and autonomously guided missiles promised to eliminate the pilot's requirements to detect his foe visually and then maneuver into a position close behind it. The F-15 sought to reduce the complexity of the F-4 by further automating the tasks that had previously necessitated a GIB. With the F-22, even those information management tasks succumbed to automation. But the automation in each aircraft was always accompanied by new tasks. Sometimes these tasks were necessary to enable the automation, as was the case in the F-4 Phantom. Other times, the humans pursued new tasks that were previously deemed infeasible, like sorting. These shifts in tasks were usually unforeseen and emerged only through an iterative process of negotiating and renegotiating the human-machine relationships.

As new tasks emerged, the human operators had to develop new skillsets. The transition could be disconcerting to those of previous generations who had staked their reputations on performing the most burdensome but now-automated tasks. To them, the automation was deskilling. Even a former CSAF who had witnessed first-hand the evolution in pilot tasks from aircraft like the F-86 through the F-15 remarked that he "would never have been interested in becoming today's fighter pilot" because they were too often relegated to "simply transporting ordnance".[87] But, in retrospect, one of the great ironies throughout this period is that the automated systems the pilots often feared would relegate them to the sidelines more often generated new imperatives for highly-skilled human pilots to remain tightly-integrated within the system.

The fighter pilot's transformation has gone largely undetected in the public sphere. A simple, one-dimensional job description like *fighter pilot* does not lend itself to the nuances

86 C. Brose, "The new revolution in military affairs: war's sci-fi future", *Foreign Affairs,* Vol.98, No.3, May/June 2019.

87 Welch, interview.

of what fighter pilots actually do in the cockpit – hence the importance of developing a cognitive ethnography to help us uncover the critical relationships between the task, the equipment, and the human operator. But fighter pilots also have little incentive to discuss this transformation with outsiders. Since the first silk-scarved aviators took to the skies in fabric-covered aircraft, fighter pilots have been celebrated in print and film as uniquely endowed to slip earth's surly bonds, possessing a cunning wit, cat-like reflexes, and hawk-like vision. Much has changed about flying a fighter jet over the last five decades, but the fact that today's pilots still thunder into the skies provides a powerful and inviolable connection to the intrepid aviators that went before them. Our understanding of how automation affected them, and how it could affect us, suffers because of it.

Thus, revisiting the history of USAF fighter aviation is particularly useful because it illuminates the pervasiveness of what Mindell described as the three myths of autonomy, and it validates his assessment that "automation often changes the type of human involvement required and transforms it but does not eliminate it".[88] Just as they have in the past, these three myths distort our understanding about autonomy in the future, and AI's potential within it. Whether aided by AI or not, the central question remains: what is the goal of the automation? Is it for our machines to replace us or to complement us? These are important questions, especially when we are talking about hypothetical AI-empowered, terrorist-hunting drones.

88 Mindell, *Our Robots, Ourselves*, p.10.