DECEPTION: MANIPULATING PERCEPTION IN AIR WARFARE

BY

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The undersigned certify that this thesis meets master's-level standard of research, argumentation, and expression.

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DISCLAIMER

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Air Force, or Air University.

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ABSTRACT

Early military theorists and philosophers recognized that deception is a fundamental part of war. Although camouflage, concealment, and deception (CC&D) techniques have been used extensively throughout the history of air warfare, most historical accounts of deception in warfare focus on war on land and at sea. This paper explores the progression of CC&D techniques used in air warfare. In doing so, it analyzes what the USAF can learn from the developmental progression and employment methods of CC&D that might enable it to have a long-term advantage over its adversaries. Despite amazing advancements in aircraft and long-range offensive weapons technologies, a corresponding progression of defensive capabilities (or restrictive air-to-air rules of engagement) present the very real possibility of aerial warfare returning to the WVR arena. When it does, high-tech USAF assets must be armed with every advantage, possibly including low-tech CC&D solutions based on historical means and methods.

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Introduction

All warfare is based on deception.

Sun Tzu

Early military theorists and philosophers recognized that deception is a fundamental part of war. Although camouflage, concealment, and deception (CC&D) techniques have been used extensively throughout the history of air warfare, most historical accounts of deception in warfare focus on war on land and at sea. This paper explores the progression of CC&D techniques used in air warfare. In doing so, it analyzes what the USAF can learn from the developmental progression and employment methods of CC&D that might enable it to have a long-term advantage over its adversaries.

The first chapter discusses the use of aircraft camouflage in war, beginning in World War I (WWI) and continuing into the modern day. This chapter shows how within-visual-range (WVR) aerial deception, using inspiration from the natural world, was optimized for a specific role and specific operating environment. Implications of aircraft camouflage employment in both mission effectiveness (bombing and night operations) and camouflage's effect on basic fighter maneuvers (BFM) are explored. This chapter also examines the relationship between military professionals and civilian painters, artists, and biologists during war as an example of mobilizing the intellectual capital of experts from traditionally non-defense-related industries.

The second chapter examines how to influence visual perception in air warfare. After addressing more CC&D lessons from nature, this chapter describes other aerial methods of visual signature reduction, including decreasing aircraft size and planform. The section ends by exploring the implications of CC&D on WVR maneuvering, and discusses how CC&D influences the observe-orient-decide-act (OODA) decision cycle and basic fighter maneuvering fundamentals.

The final chapter builds on the previous two and looks to the future of aerial CC&D. Specifically, this chapter examines how deception techniques of the past might be adapted in the present or near future to gain a crucial advantage. This section also examines the current USAF budget's planned commitment to CC&D investment, development, and procurement. Finally, other potential future CC&D capabilities and aerial deception methods are also explored.

This paper highlights the importance of CC&D in air warfare. Building on the lessons of survival found in the natural world, it also explores how the US might leverage expertise from non-traditional fields to bolster CC&D in the air domain. As technology advances and the threat of detection grows for even the most high-tech modern air forces, these lessons and partnerships from the past must not be forgotten.

Chapter 1

Within-Visual-Range Aerial Deception

No rule of camouflage is more important than having the object match its background.

Psychology for the Armed Services, 1945

The creators of the first flying machines did not worry about an aircraft's color – the goal of achieving sustained flight was daunting enough. However, design improvements and advances in engine technology throughout the early 1900s led nations to recognize the military applications of aircraft. As capabilities advanced, and the aviation industry progressed from the World War I (WWI)-era aircraft built with stretched canvas or fabric over wooden frames and powered by small horsepower motors, to World War II (WWII)-era supercharged engine-driven steel and aluminum bodies, to the supersonic jet-powered lightweight titanium and advanced composite materials of the modern era, CC&D has been an integral part of air warfare. As engines became more powerful, most military aircraft transitioned to brightly colored, unit-specific paint schemes, and were sometimes specific to individual flyers, as in the case of Germany's Manfred von Richthofen, also known as the "Red Baron." While national approaches varied, most fighters and escort aircraft used these distinctive colors and marking to deconflict friendly from enemy aircraft during WVR aerial engagements – that is, primarily as a means of aerial identification. At the same time, bombers and surveillance aircraft began employing specialized color schemes to avoid detection by enemy fighters – primarily as a means of camouflage.

Visual deception methods dominated early air warfare. Attempting to hide from interceptor aircraft, air forces in WWI painted or dyed the fabric skins of aircraft to match the intended operating environment. As early visual deception methods were developed for air warfare, they were balanced with the need for national markings used to discriminate between friendly and enemy aircraft. The fundamental tension in this balance is prevalent throughout the development of aerial CC&D, and still exists to this day. The following sections address the paradox between aerial identification and concealment, particularly as it pertains to the development of aircraft camouflage throughout WWI and WWII. Civil society's contributions to the expanded use of CC&D methods, as well as means and methods of influencing visual perception in air warfare are also discussed, as is camouflage's effect on basic fighter maneuvering fundamentals.

Aircraft Camouflage in WWI

For fighter aircraft, WWI marked the beginning of the identification versus camouflage struggle. In an era of close-in, aggressive visual maneuvering where wood-framed, fabric-covered aircraft ruled the skies, differentiating between friend and foe was difficult due to similarities between the many types of aircraft flown. Because of this, bright colors and large markings served as primary means of discrimination. National approaches varied in color schemes used, as did methods of general camouflage employment. In almost all cases, however, WVR deception was optimized for a specific role and a specific operating environment.

At the outset of WWI, the standard aircraft covering utilized clear doped fabric stretched over wooden frames.[1] Paint or other dying materials were used to strengthen the material and protect it from the harmful effects of the sun. Weight, however, was a critical issue due to the underpowered engines of the day.

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[1] W. M. Lamberton, *Fighter Aircraft of the 1914-1918 War*, ed. E. F. Cheesman (Letchworth, Herts: Harleyford Publications Limited, 1960), 186.

Although France had begun using large national insignia, based on the tricolor Revolutionary roundel or cockade, on its aircraft in 1912, British aircraft began WWI without distinctive markings. This changed in the fall of 1914, when British aircraft "were fired upon from the ground by friend and foe alike," after which a Union Jack was painted on all aircraft.[2] The Union Jack, however, was soon discovered "to be indistinguishable from the German cross at moderate heights," so "the French roundel form was adopted by the Royal Flying Corps…with the colors reversed."[3] Most other Allied nations that flew during the war, including Italy, Belgium, and Russia, adopted similar methods of using the roundel theme for identification purposes. US aircraft of the American Expeditionary Force later employed similar methods.[4]

In addition to the large national insignia that adorned the tops, bottoms, and tails of their steeds, fighter pilots painted brightly colored personal and unit markings on their aircraft. Flying units developed their own color schemes, mascots, and symbols, rivaling modern sports teams in their creativity and pride. In many cases, conspicuous personal emblems were painted on an aircraft's fuselage. In others, such as the case of the infamous "Red Baron," Manfred von Richthofen's aircraft was painted almost entirely bright red. Later, all aircraft in his *Jasta 11* squadron included bright red in their paint schemes. Even the loudest color schemes, however, did not prevent attempts at aerial deception.

As will become clear, the study of nature greatly influenced most forms of camouflage. Using bright colors to either intimidate or confuse an attacker is seen in many species in the natural world. Several types of butterflies, amphibians, and fish possess bright colors or large,

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[2] Lamberton, 184.
[3] Lamberton, 184.
[4] Lamberton, 184.

distinct shapes resembling eyes on various parts of their bodies, presumably with the intent to draw an attacker's attention away from more vulnerable parts.

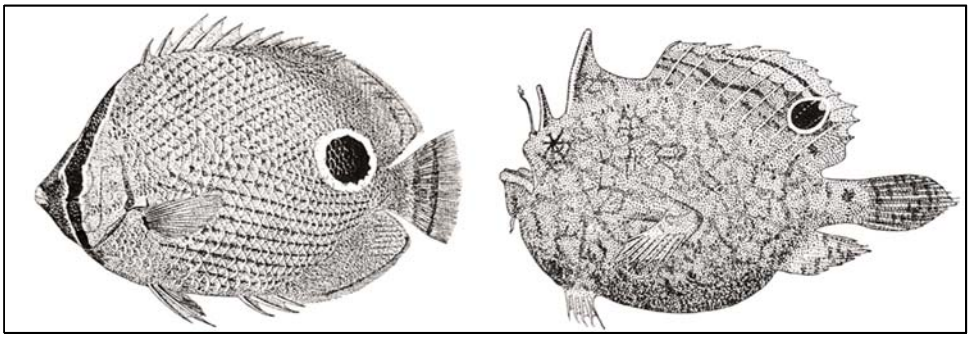

Figure 1: Manipulating Attacker Perception in Nature
Source: Adapted from Tim Newark, Camouflage (New York, NY: Thames & Hudson Inc., 2007), 34.

Like this survival mechanism found in certain types of vulnerable or edible species,[5] some paint schemes employed optical illusions to draw fire away from "the most vulnerable point of all – the pilot."[6] Allied nations conducted experiments using conspicuous designs that skewed the standard paint schemes and locations of national insignia, with the intent of disrupting the aiming point of attacking aircraft.

[5] Tim Newark, *Camouflage* (New York, NY: Thames & Hudson Inc., 2007), 34–35.
[6] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 185.

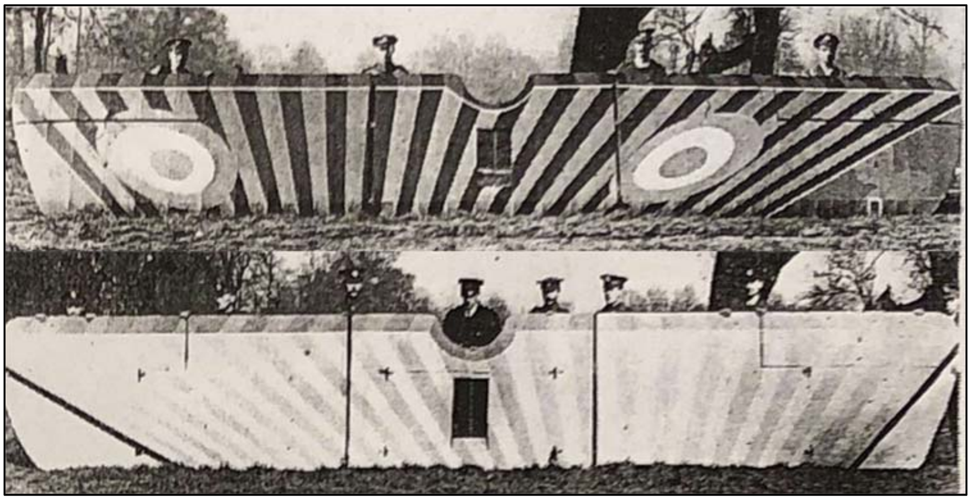

Figure 2: Manipulating Attacker Perception in WWI
Source: Adapted from W. M. Lamberton, Fighter Aircraft of the 1914-1918 War, ed. E. F. Cheesman (Letchworth, Herts: Harleyford Publications Limited, 1960), 185.

The French are credited with the first military employment of camouflage, although it was initially employed in the land domain. In 1915, Lucien Guirand de Scevola, an artist serving in the French infantry, proposed an idea to create a "section de camouflage" within the French infantry.[7] The idea was soon adopted by the Battalion of Royal Engineers, who "set up the British Camouflage Service in 1916, following a suggestion made by the portrait artist Solomon J. Solomon."[8]

US military camouflage also began in WWI, and drew heavily on the theories of naturalist and artist Abbott H. Thayer, who published *Concealing Coloration in the Animal Kingdom* in 1909.[9] Possibly building on the theories of evolutionary adaptation in nature, Thayer's observations included the concepts of countershading, mimicry, and disruptive coloration. Thayer described countershading as a

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[7] Henrietta Goodden, *Camouflage and Art: Design for Deception in World War 2* (London: Unicorn Press, 2007), 10.
[8] Goodden, 10.
[9] Goodden, 12.

phenomenon found in nature "where the lower part of the body is of a lighter tone than the upper surfaces and the contrast between the two is blurred."[10] Similar to various types of land mammals, "many species of fish have countershading to protect them from predators, showing dark brown or green when seen from above and silvery blue tones when viewed from below."[11] Mimicry, Thayer observed, involved a creature imitating its surrounding habitat. Disruptive coloration involved breaking up the surface continuity (shape or outline) of a creature to confuse the perception of an observer.[12] Thayer's principle of "disruptive coloration" showed how blocks, patterns, and patches of color help to break up the visual outline of an animal, allowing it to blend into a higher number of backgrounds.[13] The goal of this type of camouflage is to have portions blend in with its surroundings, with the non-blending colors revealing an unrecognizable shape.

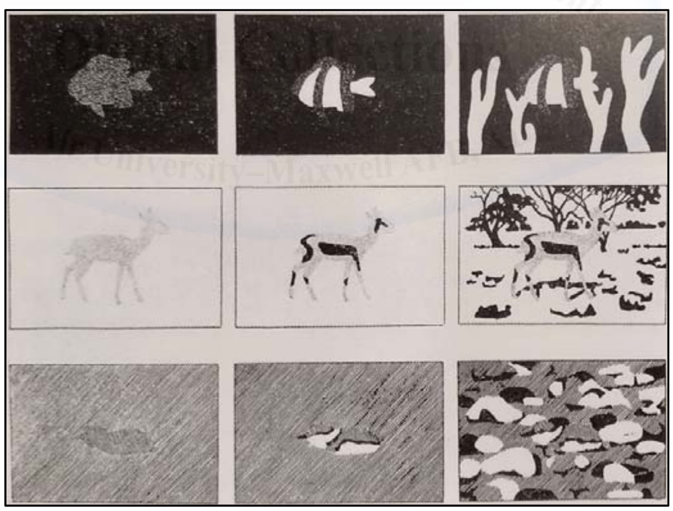

Figure 3: Disruptive Coloration in Nature
Source: Tim Newark, Camouflage (New York, NY: Thames & Hudson Inc., 2007), 31.

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[10] Goodden, 12.
[11] Seymour Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II* (London: Hawthorn Books, Inc., 1979), 5.
[12] Goodden, *Camouflage and Art: Design for Deception in World War 2*, 12.
[13] Newark, *Camouflage*, 22–24.

Several other aerial deception methods spawned from natural phenomenon. Some involved painting fighter escorts to look like bombers or reconnaissance aircraft, while others utilized a more direct application of mimicry and disruptive coloration.[14] Ernst Udet, the WWI German Ace with 62 air-to-air victories[15] who ranked second only to von Richthofen, and who was also eventually a commander of the famed *Jasta 11*, at times employed a different type of aerial deception. Mounting a rearward-facing tin head on the back of his Fokker, Udet likely assessed that Allied fighters would either overestimate his ability to fire towards his tail, thereby avoiding his "six," or, understanding most two-seaters were slower and more vulnerable, underestimate his aircraft's maneuverability.[16] Either way, the deception was intended to slow or interrupt an aerial attacker's decision-making cycle.

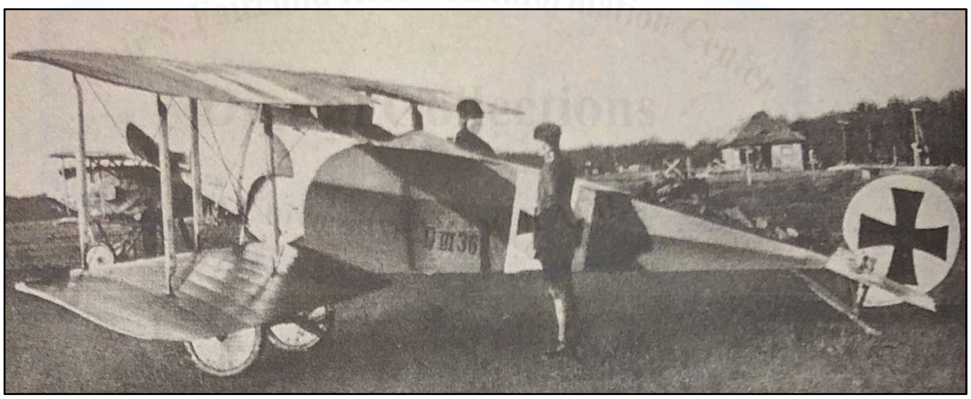

Figure 4: Artificial German Tail-Gunner
Source: Oberleutnant Ernst Udet, Ace of the Iron Cross, ed. Stanley M. Ulanoff, First Arco (New York, NY: Arco Publishing, Inc., 1970), 78d.

Aircraft camouflage was introduced generally by all WWI air forces in 1916, "and from then onwards there were the conflicting requirements

[14] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 191.
[15] Oberleutnant Ernst Udet, *Ace of the Iron Cross*, ed. Stanley M. Ulanoff, First Arco (New York, NY: Arco Publishing, Inc., 1970), 152.
[16] Udet, 78d.

of bright colors for ease of identification and drab colors for concealment."[17] After 1916, British aircraft were painted a khaki-green color, but this was mainly because the green pigments had proven effective at protecting against the sun's harmful rays. Although not primarily intended for use as camouflage, later experiments found that solid khaki-green or olive-drab green colors blended very well into many different environments and backgrounds, especially during periods of low light.[18]

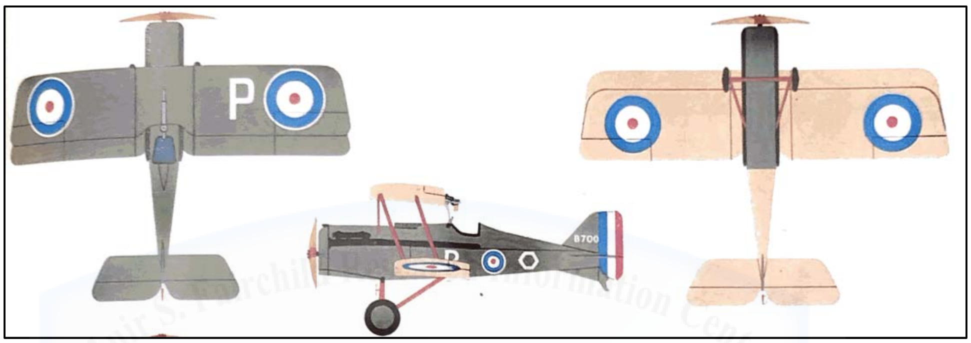

Figure 5: Typical British Coloring Scheme, 1916-1918
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 33.

France utilized "a standard two-color [(brown and green)] disruptive pattern for its low-flying aircraft, and an aluminum doping for those dedicated to high-altitude patrols.[19]

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[17] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 186.
[18] Martin J. Dougherty, *Camouflage at War: An Illustrated Guide from 1914 to the Present Day* (New York, NY: CHARTWELL BOOKS, 2017), 68. Insurance companies have data to prove that vehicles painted in these shades of green are involved in many more wrecks than other colors, especially around dawn, dusk, or periods of reduced lighting.
[19] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 187.

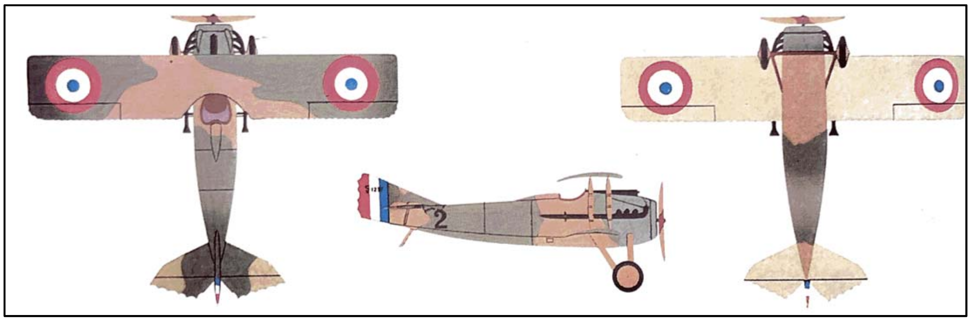

Figure 6: French Disruptive Camouflage Pattern, 1917-1918
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 34.

French pilots also experimented with decorative and multi-colored finishes, in some cases designed to simulate fish scales—another nod to the world of nature.[20]

The Germans were the first to employ aircraft camouflage in WWI.[21] Germany experimented with "various dappled two-color schemes," until the German Air Service Headquarters officially recommended "shades of dark green and lilac" in 1917.[22] To both aid in concealment and save weight, the Germans developed printed camouflage fabrics for use on aircraft starting in 1917.[23] The Germans also assessed that "disruptive patterns were the best method of camouflaging moving objects that could not easily be made to merge into a constantly shifting background."[24] Interestingly, this led them to develop multicolored patterns arranged in hexagonal or polygonal shapes. This "lozenge" pattern, as it came to be known, was printed on fabric and used on many of its Fokker aircraft throughout the last two years of WWI.[25]

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[20] Lamberton, 188.
[21] Guy Hartcup, *Camouflage: A History of Concealment & Deception in War* (New York: Charles Scribner's Sons, 1980), 14.
[22] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 187.
[23] Lamberton, 187.
[24] Newark, *Camouflage*, 68.
[25] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 188.

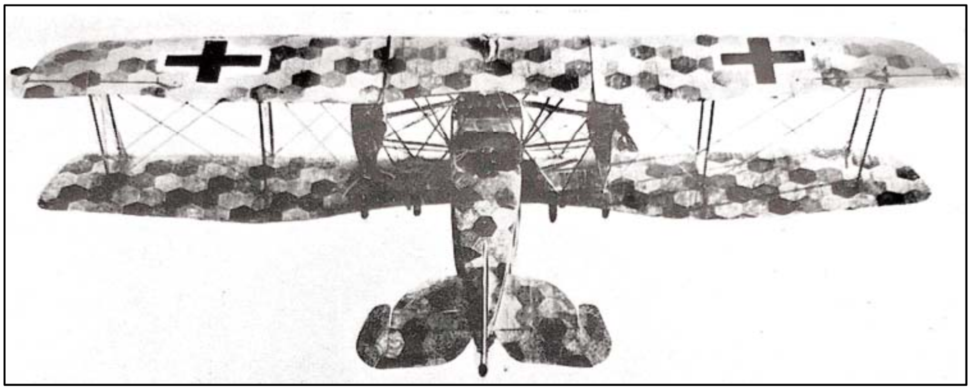

Figure 7: German Lozenge Camouflage Pattern
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 61.

Building on the German Air Service Headquarters' recommendation of shades of dark green and lilac, additional lozenge patterns were tested on German bombers and reconnaissance aircraft. Initially, these included mainly various shades of purple and gray, but later included combinations of "greyish green, greyish blue, mauve, ochre, and pink."[26] These patterns were also reproduced and distributed via printed fabrics, and applied to bombers on "areas other than lifting surfaces."[27] During the war, the Germans were seemingly very pragmatic in their approach to bomber camouflage testing, choosing to continually refine the camouflage colors used based on those that survived previous bombing raids.

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[26] W. M. Lamberton, *Reconnaissance & Bomber Aircraft of the 1914-1918 War*, ed. E. F. Cheesman (Letchworth, Herts: Harleyford Publications Limited, 1962), 199.
[27] Lamberton, 199.

Figure 8: Typical German Lozenge Camouflage Colors
Source: Adapted from Tim Newark, Camouflage (New York, NY: Thames & Hudson Inc., 2007), 69.

While fighter aircraft of WWI sported bright colors and large, distinctive emblems, reconnaissance and bomber aircraft mostly adopted an opposite approach, and instead pursued camouflage as a way of avoiding detection by defensive fighter sweeps. In mid-1917, British experiments with aircraft camouflage took many forms. "Irregular patterns of dark and light khaki" on one aircraft were compared with "shades of red and brown" on another.[28] Observers noted that blues and greens might improve the khaki pattern, and additional aircraft were tested using altered schemes. Eventually, the British settled on a scheme that utilized three main shades (brownish-green, light brownish-green, and light bluish-green) on upper surfaces and "glossy pure white undersurfaces."[29] France's standard camouflage scheme in 1917 was similar to the British, employing a "green and light brown" finish on top

[28] Lamberton, 194.
[29] Lamberton, 194.

surfaces and either clear or gray undersurface.[30] Aircraft produced within the United States were generally either greyish or olive-drab overall, while the aircraft of the American Expeditionary Force generally retained the French or British standard camouflage schemes, depending on the nation from which the aircraft originated.[31]

Additional British experiments with aircraft camouflage patterns continued in 1918.[32] Early in 1918, both the British and Germans recommended that "the upper surfaces of lower planes of biplanes be lighter to compensate for the shadow bestowed by the upper plane."[33] While the British generally used khaki for aircraft undersurfaces, Germans generally used light gray.[34] Differentiating colors or shades of colors between darker upper and lighter lower surfaces is a common phenomenon found in nature, and is referred to as countershading.

Like the optical illusion-type paint schemes previously mentioned, Britain also experimented with conspicuous finishing designs intended to spoil an attacker's ability to line up an easy shot. One test involving a checkered pattern of one-foot, black and white squares was found to break up the outline and distinguishing features of the target aircraft. Another tested the same idea with larger one-yard squares, "leaving a portion of the wing in the usual khaki."[35] However, because both designs were too easily spotted, and also because the khaki portion of the wing blended in much better with the background, "the idea of checks was abandoned."[36] While not directly found in existing literature, it is

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[30] Bruce Robertson, *Aircraft Camouflage and Markings 1907-1954*, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 47.
[31] Robertson, 34, 53–54.
[32] Hartcup, *Camouflage: A History of Concealment & Deception in War*, 14.
[33] Lamberton, *Reconnaissance & Bomber Aircraft of the 1914-1918 War*, 194–95.
[34] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 61.
[35] Lamberton, *Reconnaissance & Bomber Aircraft of the 1914-1918 War*, 194.
[36] Lamberton, 194.

possible this may have served as a precursor of future "dazzle-camo" designs to be tested in WWI and WWII.

Drawing on the idea of disruptive coloration found in nature, a different type of "dazzle-style" camouflage pattern of black, white, and blue was created by British designer and marine painter Norman Wilkinson. As a Lieutenant in the British Royal Navy, Wilkinson's idea was originally designed for warships to confuse the torpedo firing solutions of German submarines.[37] Later, Wilkinson's "dazzle-camo" idea resulted in designs intended for British aircraft.[38] Though it is unclear whether the concept was ever tested in WWI, this idea would eventually be explored again in WWII.

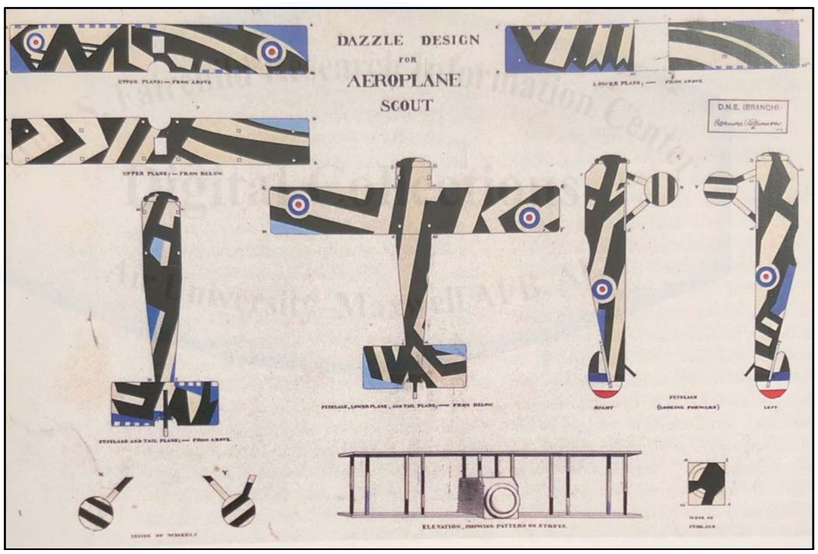

Figure 9: British Dazzle-Design Camouflage Experiment
Source: RAF Museum, as shown in Henrietta Goodden, Camouflage and Art: Design for Deception in World War 2 (London: Unicorn Press, 2007), 13.

[37] Goodden, *Camouflage and Art: Design for Deception in World War 2*, 13–14.
[38] Goodden, 13–14.

WWI Night CC&D

WWI also marked the beginning of CC&D considerations for night flying. Beginning in 1916, the Germans prohibited white markings of any kind on its night-flying aircraft.[39] Night camouflage lozenge patterns consisting of "dark green, dark blue, and black" were printed on fabric and applied to German night bombers.[40] France also specified different camouflage considerations for its day versus night-flying escadrilles, with the latter being painted either "an overall blue-black"[41] or violet, a "color considered more effective than black at night."[42]

Post-WWI

The conflict between identification and concealment continued after the Great War. Soon after WWI ended, British "conclusions were that roundels, with their white outlines, rendered nugatory existing camouflage schemes."[43] Nations were forced to develop means of assisting both ground and air observers in identifying aircraft as friend or enemy. As early as 1916, Allied nations determined that distinct, geometrical shapes or bars were easier to identify than colors from long distance, especially in poor lighting conditions.[44] When flying in large formations, some bombers also carried long red streamers to identify themselves to their squadron or flight members.[45] Large, overtly colored letters or numbers (and sometimes both) also appeared on both fighter

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[39] Lamberton, *Fighter Aircraft of the 1914-1918 War*, 184.
[40] Lamberton, *Reconnaissance & Bomber Aircraft of the 1914-1918 War*, 199.
[41] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 47.
[42] Lamberton, *Reconnaissance & Bomber Aircraft of the 1914-1918 War*, 198.
[43] Lamberton, 195.
[44] Lamberton, 195, 199.
[45] Lamberton, 201.

and bomber fuselages to aid in formation flying in the latter stages of WWI.

In January of 1921, the US Air Corps' Air Services Engineering Division released a "Report on Camouflage of Day Airplanes."[46] This report distinguished between "terrestrial (or ground) camouflage consisting of three-color patterns tailored to fit local terrain colors," and "celestial (or sky) camouflage [intended] to decrease the visibility of aircraft viewed from below."[47] Until 1921, most aircraft coverings in the US consisted of clear doped fabric, which had a slight yellow tint. Tests conducted for this report showed that a normal, clear doped aircraft "became invisible [to ground observers] at an altitude of 17,000 feet," while aircraft painted in sky camouflage disappeared at 10,000 feet. While it is unclear whether the US was aware of similar British and German conclusions from 1918, the report also explored "shadow shading," and determined that lighter colors should be used "between wings and beneath the tail" sections.[48] Finally, the report recommended that "one or both national insignia should be eliminated from the wings of any camouflaged aircraft."[49] Faced with the realities of decreased military funding post-WWI, however, the Air Corps did not fully implement the report's recommendations, as "camouflage in a peacetime air force was a low priority."[50]

Camouflage testing, however, continued throughout the 1930s. The Air Corps Materiel Division (which succeeded the Engineering

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[46] Dana Bell, *Air Force Colors Vol. 1 1926-1942* (Carrollton, TX: Squadron/Signal Publication, Inc., 1979), 54.
[47] Bell, 54.
[48] Bell, 54.
[49] Bell, 54.
[50] Bell, 54.

Division) "became interested in a temporary means of covering the yellow flying surfaces of aircraft during the annual field maneuvers."[51] The result was an olive drab colored, temporary water-based paint that was durable, relatively cheap, could be applied in a matter of hours, and added about ten pounds of total weight. In 1932, virtually the same 1921 test was reproduced using temporary water-based paints, using color schemes recommended from the previous report. Aerial surveys were conducted between 1932-1935 over the US, and new color combinations were recommended for operations over different types of terrain. In the words of one author, "the idea was flexibility: inappropriate schemes could be removed and replaced without building successive layers of paint."[52]

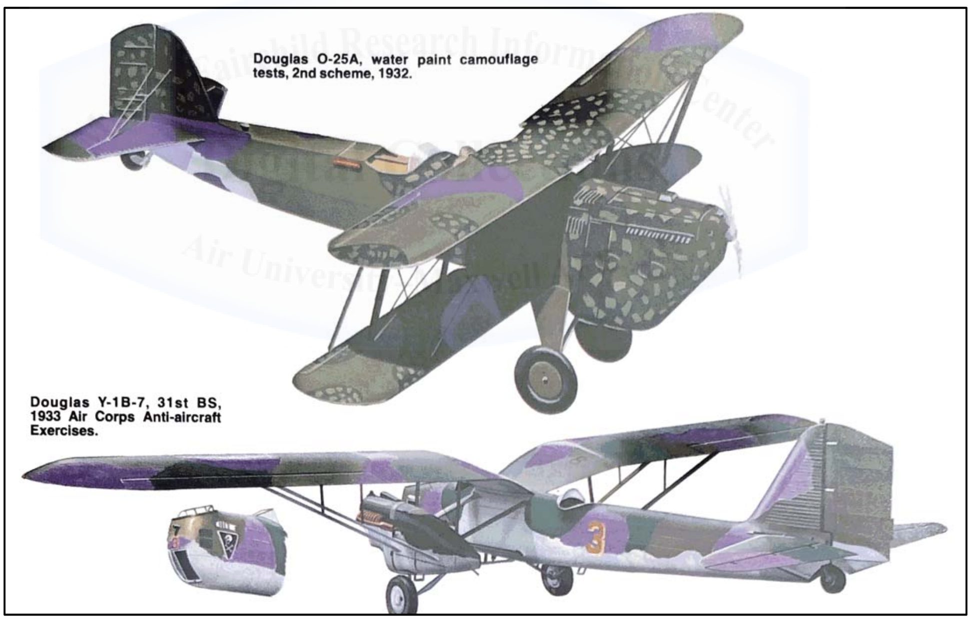

Figure 10: US Temporary Water-Paint (top) & Ground/Sky (bottom) Camouflage Test Schemes, 1930s
Source: Dana Bell, Air Force Colors Vol. 1 1926-1942 (Carrollton, TX: Squadron/Signal Publication, Inc., 1979), 44.

[51] Bell, 54.
[52] Bell, 54.

The sky camouflage scheme generally employed a "light blue, mottled with irregular patches of white [or] aluminum,"[53] but a "light blue scalloped with purple"[54] was also used, particularly when a ground and sky scheme was applied to the upper and lower surfaces, respectively. The ground scheme varied based on terrain and season. During autumn on the east coast, for example, a combination of "dark green, purple, buff (mix of olive drab and white), and reddish-brown (mixed from a locally procured brick color)" was found to be the most effective at blending in with the terrain below. A 1936 War Department report on Aircraft Camouflage recommended five ground scheme designs, which were intended to "be as simple as possible" and treated as guides that "need not be adhered to in detail."[55] The ground schemes recommended in this report employed mainly large, irregular patches of green, gray, and olive drab. Snow and desert camouflage schemes were also tested throughout the 1930s, and the War Department's 1936 report issued guidelines for various types of aircraft and differentiated between cultivated and wooded areas, desert areas, areas with snow cover, and provided recommendations for sea camouflage.[56]

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[53] War Department, "Airplane Camouflage" (Washington, DC, 1936), 1.
[54] Bell, *Air Force Colors Vol. 1 1926-1942*, 55.
[55] War Department, "Airplane Camouflage," 2.
[56] War Department, 5.

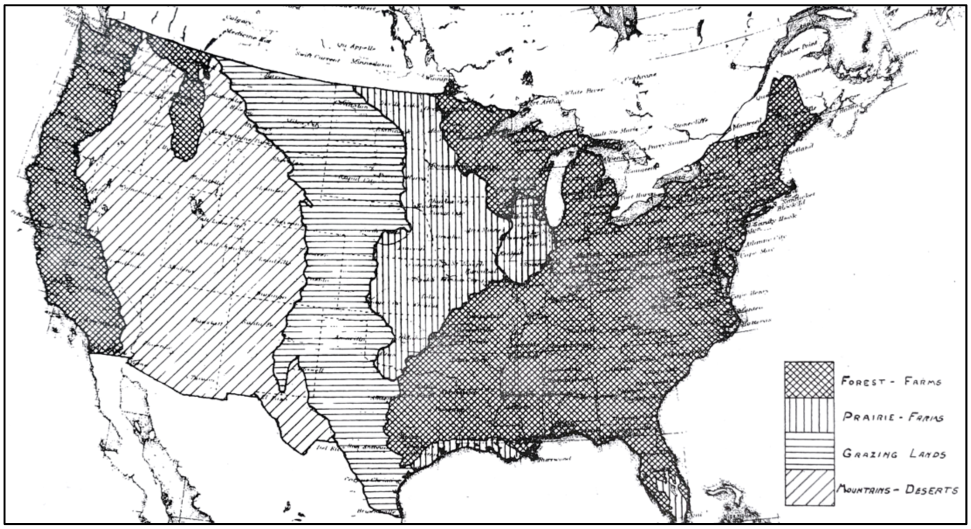

Figure 11: War Department's Recommended Camouflage Map, 1936
Source: War Department, "Airplane Camouflage" (Washington, DC, 1936), 6.

Between 1925 and1937, most British aircraft were finished in silver or gray for day-flyers, and dark drab green for night bombers. Conspicuous unit and personal markings continued to be added, and, as peacetime identification requirements took priority over wartime concealment concerns, unique serial numbers and "tail flashes" for individual aircraft were also added.[57]

The camouflage paint schemes of the US Army Air Corps in the 1930s were governed by Technical Order (T.O.) 07-1-1, AIRCRAFT MARKINGS, INSIGNIA AND CAMOUFLAGE.[58] Since the paint at that time had a "useful life of about one month under average service conditions," most camouflage paint schemes were applied in only a temporary manner.[59] Standard practice of the day considered the "upper and lower surfaces of the airframe as separate camouflage problems,

[57] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 65–81.
[58] Ross Whistler, "United States Air Force Camouflage 1933-1969" (Dover, Massachusetts, 1969), 1.
[59] Whistler, 2.

classified by the background against which they would normally be viewed."[60] This resulted in the top surfaces of aircraft being painted with a "ground camouflage" pattern, consisting of "dark shades of green, olive drab, and purple or mauve," and the bottom surfaces being painted in a "sky camouflage" pattern, consisting of patches of purple on a light blue base for daytime, or black for nighttime.[61]

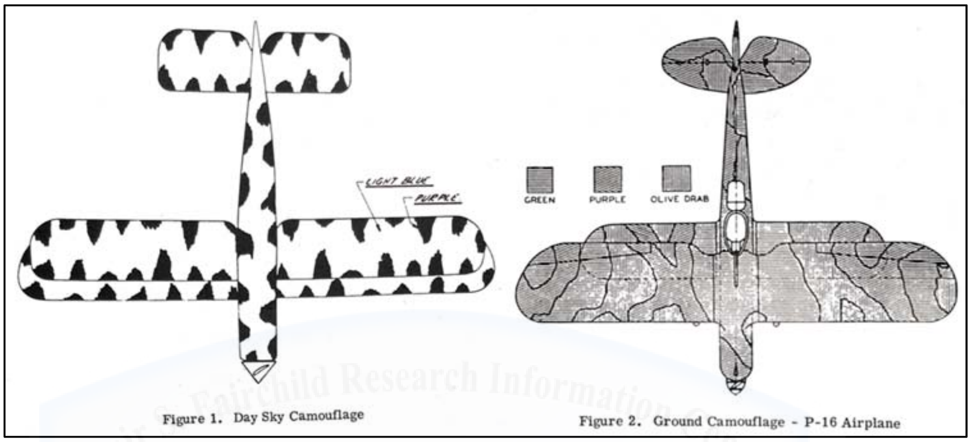

Figure 12: Standard US Camouflage Schemes, 1936
Source: Adapted from Ross Whistler, "United States Air Force Camouflage 1933-1969" (Dover, Massachusetts, 1969), 3.

These US ground and sky camouflage patterns changed slightly in 1936, with the ground camouflage adopting either "green, gray, and olive drab patches" for operations over normal terrain, "sand, gray, and olive drab" for desert terrain, or "flat white mottled with gray" for winter operations.[62] A "sea camouflage" pattern consisting of "green, dark blue and dark green patches" was also added for operations over water.[63] Sky camouflage became mostly "light blue, mottled with irregular patches of white and aluminum," while "night sky camouflage remained black."[64]

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[60] Whistler, 1.
[61] Whistler, 1.
[62] Whistler, 2.
[63] Whistler, 2.
[64] Whistler, 2.

During the interwar period, in an era known as the Golden Age of Aviation, stylized squadron markings were proudly and brightly displayed on most fighter biplanes.[65] Starting in 1937, however, Britain and other European nations began increasing production of aircraft in anticipation of the coming war, and a typical dark brown and dark green camouflage scheme became the standard finish of aircraft coming off the production lines of manufacturers.[66] "Undersurfaces remained in silver on [British] fighters until mid-1938, when it was replaced by sky-grey."[67] After that, the undersurface of fighters was divided down the middle, with one half painted black and the other half either sky-blue or sky-gray. British bombers, however, painted the undersurfaces all-black, some of which changed in 1940-1941 to light olive drab or gray.[68] Transport and civil aircraft also adopted standard camouflage paint schemes during WWII.[69]

WWII Night CC&D

The 1936 War Department report on "Aircraft Camouflage" recognized that "the need for and the value of camouflage applied to airplanes for night operations are dependent on several factors," including searchlight illumination levels, weather conditions, phases of the moon, and the color of an aircraft's finish.[70] While impossible to account for every weather condition, moon illumination level, or observer location, the report found that a matte black finish had "about 20 percent the visibility of the standard yellow [(clear dope)] finish."[71] In

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[65] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 85.
[66] Robertson, 82.
[67] Robertson, 82.
[68] Robertson, 82, 86.
[69] Robertson, 86.
[70] War Department, "Airplane Camouflage," 2.
[71] War Department, 2.

1938, the US experimented with applying all-black (Black-33), temporary water-based paints to the undersides of B-17 bombers as part of its annual Anti-Aircraft Maneuvers field trials.[72] When the temporary paint experiments ended in the US, most night-flyers reverted to an overall flat black or the early 1940s-standard olive drab upper and neutral gray lower scheme. Some bombers flown by Ferry Command, however, particularly those destined for the RAF, came off the assembly line in RAF Night Bomber colors ("dark earth and dark green" upper over flat black under surfaces).[73] In Britain, "an official night-fighting camouflage of overall black came into effect from December, 1940" for night fighters and bomber aircraft. In addition to gray or dull-red lettering for serial numbers and codes, as well as subdued roundels, a special coating called RDM2 was applied to these night-flying types, "which gave a velvety non-reflective surface."[74]

French night-flyers generally adopted similar methods, but faced a uniquely self-imposed obstacle to night camouflage. To ease identification of friend or foe, French leaders insisted on keeping its national emblem of blue, white, and red bars on the vertical tails of its aircraft throughout the 1930s.[75] When the aerial combat of WWII began, Royal Air Force squadrons and other Allies flying fighters in France were forced to re-implement their own rudder striping, in the colors of each respective nation. This resulted in large white bars over the tail portions of each nation's fighter fleet, which compromised even the best night camouflage schemes.[76] Post-1942, as daylight losses mounted, British bombers adapted paint schemes optimized for flying at night. Bombers

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[72] Bell, *Air Force Colors Vol. 1 1926-1942*, 69.
[73] Bell, 84.
[74] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 98.
[75] Robertson, 98.
[76] Robertson, 99.

assigned to Bomber Command were mainly painted with the temperate land scheme (dark earth and dark green) on upper surfaces, with black painted on undersurfaces and approximately three-quarters of the way up the sides of the fuselage to avoid search lights during night bombing raids. In addition to minimizing the white stripe on the rudder markings, most British night bombers also used gray or dark red for the serial numbers.[77] Many German bombers, also responding to heavy daytime losses, adopted similar night paint schemes, with some utilizing a gray mottled camouflage pattern on upper surfaces and black on lower surfaces, and others adopting an overall black scheme.[78]

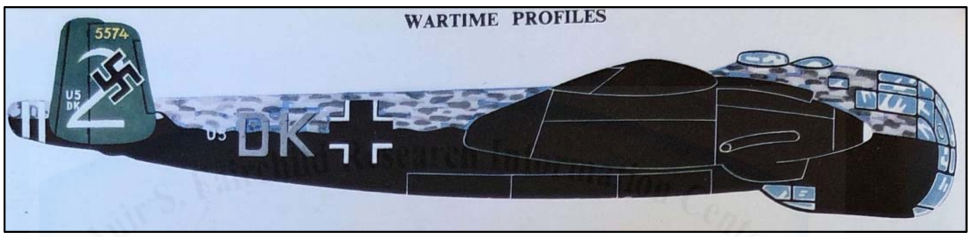

Figure 13: Typical German Night Bomber Paint Scheme
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 122.

Although promising in theory, the idea of employing temporary paint was never standardized in the US, and in 1940, the implementation of permanent camouflage paint schemes brought an end to further temporary paint testing. In May 1939, Major General Hap Arnold, Chief of the Air Corps, "requested that Materiel Division research factory application of permanent camouflage paint to combat aircraft."[79] Citing the difficulty of blending into "changing background conditions and [the] added cost, weight, and drag" associated with permanent

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[77] Robertson, 107.
[78] Robertson, 122, 155.
[79] Bell, *Air Force Colors Vol. 1 1926-1942*, 70.

paints, the Materiel Division initially resisted the idea of permanent camouflage, and instead continued to recommend the temporary water-based paint method.[80] General Arnold was unsatisfied with this response, and in August, 1939 directed the Materiel Division to "experiment with permanent camouflage," and also directed that the "Air Corps Board at Maxwell Field make a study of various colors and patterns."[81] General Arnold also required both organizations to submit partial reports as the testing progressed, so that "findings could be applied long before the final report" was released.[82]

In the late 1930s, Germany camouflaged its operational aircraft in a "three-colored splintered camouflage" consisting of "dark brown, green and grey" upper surfaces and light blue undersurfaces.[83] In 1938, this three-color scheme was superseded by a newly patterned, two-color combination of black-green and dark green."[84] British reports in 1940 of German aircraft encountered during the Battle of Britain involved "dark grey Ju-87s, dark green Me-110s with sky-blue bellies, and pale green and silver Me-109s."[85] Beginning in 1940, many German fighter aircraft types employed the spotted camouflage scheme, which involved the splinter-type design on the upper surfaces, and a grey spotted, splotchy, or wavy pattern on the sides of the fuselage.[86] Many bomber and transport types utilized the splinter camouflage pattern, or were painted dark grey on upper surfaces.[87] In almost all cases, light blue was the

[80] Bell, 70.
[81] Bell, 70.
[82] Bell, 70.
[83] Karl Ries Jr., *Markings and Camouflage Systems of Luftwaffe Aircraft in World War II, Vol. II* (Finthen bei Mainz: Dieter Hoffman, 1965), 9.
[84] Ries Jr., 9.
[85] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 154.
[86] Ries Jr., *Markings and Camouflage Systems of Luftwaffe Aircraft in World War II, Vol. II*, 9, 101–12.
[87] Ries Jr., 101–12.

color of choice for the undersurfaces, and, regardless of paint scheme, all German aircraft sported large, distinctive German crosses on the wings and fuselages and Nazi swastikas on the tail.[88] During this time, a German company developed a method of temporarily applying "varnish with a non-drying glyptal resin" over a normal finish, resulting in "a completely new technique in aircraft camouflage."[89] This new technique allowed the Germans to apply a temporary camouflage scheme to an aircraft for a dedicated operation over a specific area. Other nations, including the US, would later test similar temporary paint application methods to "meet changing roles in different theaters."[90]

In 1940, prior to direct US involvement in WWII, "Air Corps aircraft were coming off the production lines unpainted" before being delivered to Britain.[91] This served primarily as both an expedited manufacturing and cost-savings technique, but was also partly due to the weight restrictions of the day, and partly due to the desire of customer nations to paint aircraft themselves. By the fall of 1940, however, the Air Corps Board at Maxwell Air Base, in coordination with the Material Division at Wright Field (per direction from General Arnold), recommended to renew the application of camouflage paint schemes to new aircraft. As opposed to previous paint schemes, these colors were now standardized by US Army Quartermaster Specification 3-1, and included "Dark Olive Drab-31, Neutral Gray-32, Black-33, and Sea Green-28" as the primary camouflage colors.[92] The standardization[93] of paint scheme colors was a

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[88] Ries Jr., 101–12.
[89] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 154.
[90] Robertson, 154.
[91] Whistler, "United States Air Force Camouflage 1933-1969," 2.
[92] Whistler, 2, 4.
[93] The standard color guidelines, eventually consolidated and released as AAF Bulletin 48, COLOR CARD FOR TEMPORARY CAMOUFLAGE FINISHES, were utilized between May 1942 and August 1954. Source: Whistler, 3-5.

shift from previous practice, which allowed those responsible for operating the aircraft to decide on the closest color match for the operating area. Soon after US Army Quartermaster Specification 3-1 was released, the Materials Laboratory at Wright Field, Ohio, "developed flat lacquer paints in camouflage colors" and issued Air Corps Bulletin 41, COLOR CARD FOR CAMOUFLAGE FINISHES.[94] Air Corps Specification 24114, CAMOUFLAGE FINISHES FOR AIRCRAFT, was released in October 1940, and "enabled the Air Corps to receive its new aircraft already camouflaged" from the manufacturer.[95] The standard color scheme of Air Corps Specification 24114 "called for Dark Olive Drab-41 upper surfaces and Neutral Gray-43 under surfaces, with the dividing line to occur 30 degrees below the point where the aircraft exterior was vertical."[96]

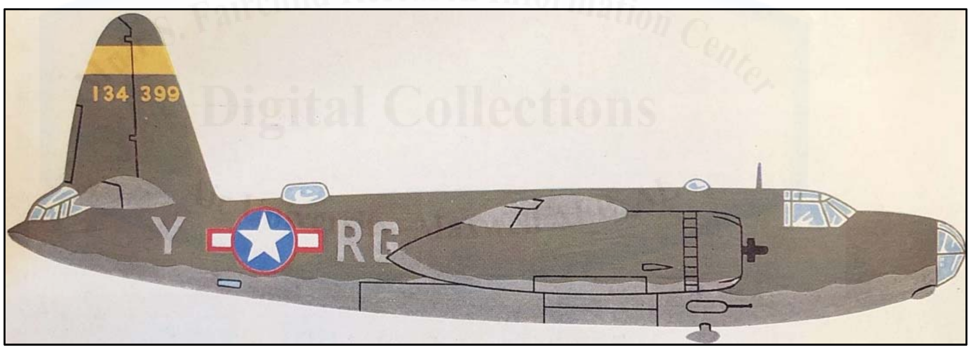

Figure 14: US Standard Color Scheme, 1940
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 122.

Also in 1940, another well-known British naturalist, Dr. Hugh Cott, was recruited to be part of the team of instructors at the newly-formed "Camouflage Development and Training Centre at Farnham

[94] Whistler, "United States Air Force Camouflage 1933-1969," 4.
[95] Whistler, 4.
[96] Whistler, 4, 6.

Castle."[97] Dr. Cott's book, *Adaptive Colouration in Animals*, built upon the work of Abbott Thayer, and was an influential text for WWII camouflage schemes.[98] John Graham Kerr, a well-known biologist and Professor of Zoology at Glasgow University, reviewed Dr. Cott's book as "the greatest comprehensive work on the subject of natural camouflage," and advocated in 1941 to the British House of Commons that "biologists, not physicists or artists, [should] head up all camouflage research and design work" in the War Cabinet.[99] Many artists, designers, playwrights, prop-makers, architects, engineers, and mathematicians were eventually recruited to assist in the development and application of camouflage services during WWII.[100] While natural camouflage ideas such as countershading and disruption were common in early national paint schemes, other methods such as mimicry (imitation) and merging or toning down were also employed by almost all nations.[101]

One of the early ways that civilian experts contributed to US aerial deception was through the development of "Haze Paint" and "Synthetic Haze Paint" in 1940.[102] In the summer of 1940, "Mr. Samual Cabot, a prominent Boston paint manufacturer, contacted the Army about a new white paint with unusual properties."[103] Mr. Cabot explained that "the pigment grains of his paint had a diameter below the wavelength of blue or violet light," resulting in "a high reflection in these color ranges."[104] In the visible light spectrum, the perceived color of an object observed by

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[97] Goodden, *Camouflage and Art: Design for Deception in World War 2*, 14.
[98] Goodden, 14.
[99] Goodden, 14.
[100] Goodden, 156.
[101] Goodden, 18.
[102] Dana Bell, *Air Force Colors Vol. 2: ETO & MTO 1942-45* (Carrollton, TX: Squadron/Signal Publication, Inc., 1980), 27.
[103] Bell, 27.
[104] Bell, 27.

the human eye (the color the eye actually sees) is the color that is not absorbed by the given object. Cabot proposed that "spraying his paint over a dark blue or black base would allow only blue and violet to be reflected, with all other colors being absorbed by the base coat. Different angles of reflection would change the degree of absorption and, in theory, match the prevailing sky background."[105] Cabot also pitched his idea to the Massachusetts Institute of Technology (MIT), who "found his theories sound and urged experimentation by USAAF's Materiel Division."[106] Around this time, the USAAF was planning to modify some of its P-38 aircraft for the photographic reconnaissance role. When initial haze paint tests using a P-43 proved promising, additional tests were conducted and Lockheed was directed in March 1942 to "paint all of its F-4s (as the photo P-38s were known) in Haze Paint."[107] P-38s converted for reconnaissance missions were also later designated as F-5s.

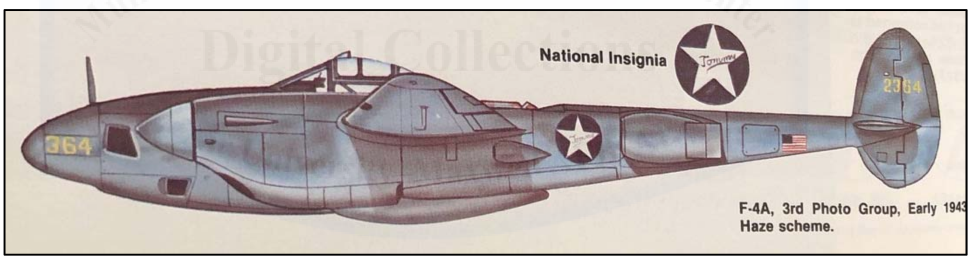

Figure 15: Haze Paint Scheme, 1942-43
Source: Dana Bell, Air Force Colors Vol. 2: ETO & MTO 1942-45 (Carrollton, TX: Squadron/Signal Publication, Inc., 1980), 36.

Though effective for high-altitude reconnaissance missions, the application and maintenance of the Haze camouflage scheme proved extremely difficult. No equipment existed to evenly or consistently apply Mr. Cabot's formula over a black base layer, and different amounts of

[105] Bell, 27.
[106] Bell, 27.
[107] Bell, 99.

Haze paint applied by hand-sprayers resulted in uneven thicknesses, which produced a wide range of reflectance and varying shades of blue. Once applied, the Haze scheme was also difficult to maintain, requiring "a full twelve hours to dry, followed by two to four man-hours removing accumulated surface dust."[108] Many paint crews required medical attention after a full day's exposure to Haze paint fumes, and the colors darkened considerably as the aircraft weathered, which rapidly decreased the effectiveness of the camouflage.[109]

Searching for a solution to many of these problems, an engineer from the paint manufacturer Sherwin-Williams Company teamed up with a 2nd Lieutenant USAAF representative and engineers from the Lockheed Vega aircraft company. The team developed an alternative high-altitude camouflage scheme they called Synthetic Haze. The Synthetic Haze used "a new blue base paint of a deep sky tone, which they called 'Sky Base Blue'. Next, they tinted a synthetic haze enamel, Flight White, to a color they named 'Flight Blue'." They sprayed the lighter Flight Blue over the darker Sky Base Blue, which created a very subtle difference in shades of blue. The Synthetic Haze scheme was applied to an F-5A, and proved very effective in tests intercepting a B-17, avoiding detection by all six observers "until it had approached within 1,000 feet."[110] Materiel Command soon "embraced the new scheme, [and] by March 1943, Lockheed had standardized Synthetic Haze Paint for its F-5As and Bs."[111]

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[108] Bell, 27.
[109] Bell, 27.
[110] Bell, 30.
[111] Bell, 30.

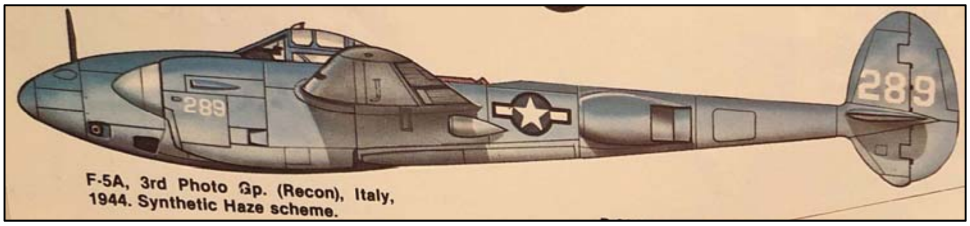

Figure 16: Synthetic Haze Paint Scheme, 1944
Source: Dana Bell, Air Force Colors Vol. 2: ETO & MTO 1942-45 (Carrollton, TX: Squadron/Signal Publication, Inc., 1980), 68.

Also in the early-1940s, at the Massachusetts Institute of Technology, the Office of Scientific Research's Camouflage Section introduced a new night camouflage color. Named Jet Black, it was "an extremely glossy and smooth paint [intended to] reflect light away from any observer not at the specular angle," which is the specific angle at which light reflects off a high-gloss or mirror-like surface.[112] In contrast, dull or rough finishes tend to diffuse incoming light in many directions, theoretically increasing the probability of detection. In 1943, Proving Ground Command experimented with the night visibility of Dull Black, Neutral Gray, and Jet Black, and concluded that all three colors "were found to be equally visible in searchlights. Additionally, Neutral Gray had a slight advantage in moonlight and the June 1943 report recommended that all night fighters be painted with standard OD/Neutral Gray camouflage."[113] Surprised by the report's findings, MIT's researchers challenged these results, and discovered that during the tests, their Jet Black paint had been mistakenly applied over an existing rough surface, resulting in a finish that was "glossy but not smooth."[114] When the tests were repeated with a correctly smoothed finish, "Jet Black was found to be totally invisible in 80% of all passes made through the searchlights," confirming the Office of Scientific

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[112] Bell, 47.
[113] Bell, 47.
[114] Bell, 47.

Research's theory.[115] This "anti-searchlight paint," as it came to be known, was eventually implemented by Northrop on its bomber assembly lines beginning in late February 1944.[116] This high-gloss Jet Black paint (also referred to as Jet 622) was employed by most US bomber units in the Pacific theater who were tasked "with night operations against the [Japanese] petroleum oil industry."[117]

In 1940, around the same time the US was adopting Air Corps Specification 24114, the British Ministry of Aircraft Production directed implementation of six standard camouflage patterns, which were based on the service's six main aircraft types, and five standard paint schemes, which used different colors based on the intended operating environment.[118]

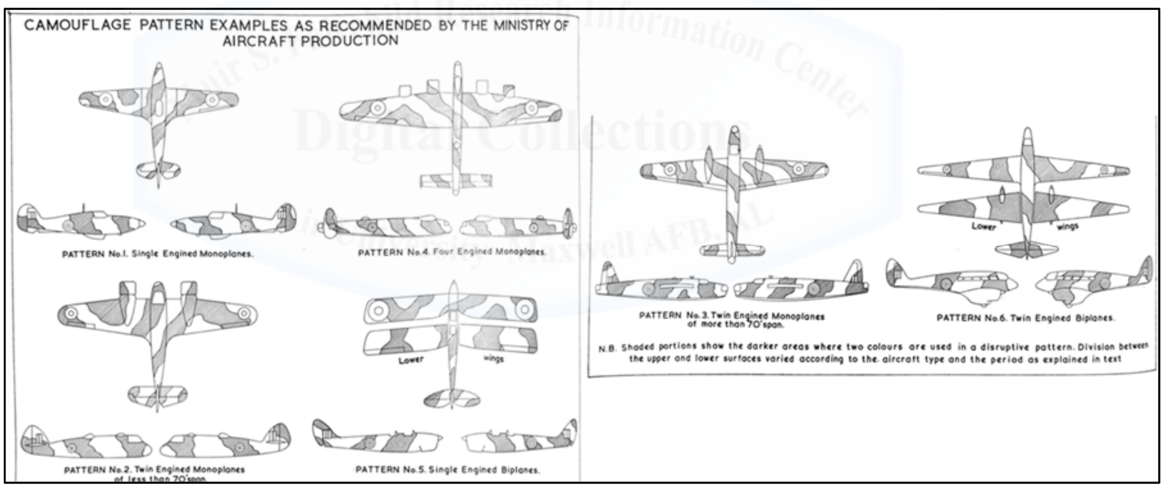

Figure 17: British Standard Paint Schemes, 1940
Source: Adapted from Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 132.

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[115] Bell, 47.
[116] Bell, 47.
[117] *Camouflage and Markings No. 19: Boeing B-29 Superfortress, U.S.A.A.F. 1942-1945* (London, England: Ducimus Books Limited, 1970), 162.
[118] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 94.

Most British production aircraft in the 1940s employed the temperate land (dark green and dark brown) or temperate sea (dark slate gray and extra dark sea gray) camouflage paint schemes.[119]

Figure 18: British Temperate Land Scheme, 1940s
Source: Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 95.

During WWII, the British "enlisted the services of a famous magician, Jasper Maskelyne, to help with concealment and decoy design."[120] The German invasion of Norway and Denmark in April 1940 mobilized the British population, and Maskelyne was no exception, vowing to "mobilize the world of magic against Hitler."[121] Maskelyne eventually joined the "Camouflage Experimental Section," and served mainly in the Middle East and North African theaters.[122] Drawing on the basic "*look over there!*" idea found in magic, the Camouflage Experimental Section thrived on manipulating the perceptions of its intended audience, which, in this case, involved enemy bombers.[123] Maskelyne's camouflage team invented several innovative CC&D

[119] Robertson, 94.
[120] Hy Rothstein and Barton Whaley, eds., *The Art and Science of Military Deception* (Boston: Artech House, 2013), 51.
[121] David Fisher, *The War Magician* (New York, NY: Coward-McCann, Inc., 1983), 10.
[122] Fisher, 46.
[123] Fisher, 12.

solutions for Allied forces, employing mirrors and other reflective surfaces extensively throughout the war.[124] In one case, his group developed and tested high-intensity, dazzle-type searchlights, which were so effective they caused both friendly test aircraft to nearly crash.[125] Other experimental camouflage units, however, were formed after Maskelyne's unit proved successful in early attempts at deceiving enemy bombers. While some artists and magicians were employed to create decoy targets during the Battle of Britain, others were employed to paint fake bomb craters on large canvases, which would be laid out on British runways to dissuade further bombing from Luftwaffe fighters and bombers. These canvases were painted to realistically imitate different times of day under either sunny or cloudy sky conditions.[126]

British camouflage transitioned from temperate land scheme with overt national markings during the Battle of Britain in 1940, to temperate sea schemes as offensive operations later advanced towards mainland Europe, and some eventually transitioned to bare metal as range and endurance became more important. An exception to this transition to bare metal trend were those aircraft dedicated to photographic reconnaissance: because successful reconnaissance missions depended on clear weather, a deep blue camouflage color that matched the sub-stratosphere was applied to British Spitfires and Mosquitos in 1943.[127]

Prompted by Pearl Harbor, the AAF commander, General Henry "Hap" Arnold, directed that all air stations apply protective measures

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[124] Fisher, 301.
[125] Fisher, 129–31.
[126] Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 49, 51, 56.
[127] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 110.

including camouflage and aircraft dispersal techniques.[128] Several schools were subsequently set up throughout the US in mid-1942 to provide camouflage training to new American military recruits. One of these schools, the Jefferson Barracks outside St. Louis, Missouri, was "directed by Major (later Lieutenant Colonel) William Pahlmann, one of America's leading interior designers."[129] Maj Pahlmann's staff included famous artists, sculptors, painters, fabric designers, architects, and stage designers for well-known plays of the day – "people who had a feel for color, for shape."[130] The school's training emphasized "that camouflage meant fooling the eye – not only covering things up, but *diverting* the enemy's attention."[131] Other schools employed Hollywood moviemakers, "art directors, scenic designers, painters, animators, landscape artists, lighting experts, carpenters, and prop men" to assist in training American troops.[132]

For the USAAF, "the year 1943 saw both the greatest effort expended on standardizing camouflage colors and the waning use of camouflage paints."[133] That year, the specification and procurement of camouflage colors was standardized across US Army and Navy aircraft after reviewing those used by "the Army Air Forces, the Bureau of Aeronautics, and the British Ministry of Aircraft Production."[134] 1943, however, also witnessed the widespread usage of radar, "reducing the protection afforded by visual camouflage."[135] Additionally, based on a shift to offensive airstrikes, the emphasis on range and endurance led to

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[128] Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 74–75.
[129] Reit, 78.
[130] Reit, 78–80.
[131] Reit, 80.
[132] Reit, 84.
[133] Whistler, "United States Air Force Camouflage 1933-1969," 6.
[134] Whistler, 6.
[135] Whistler, 10.

the USAAF conclusion that “bombers and escort fighters could no longer afford the weight and drag penalties imposed by camouflage paint.”[136] Although the exact amount of additional weight added from paint depends on the size of the aircraft, later tests revealed that as much as 176 pounds could be saved by not painting a bomber-sized aircraft.[137] In an era where bombers and long-range fighter escorts were operating near the limits of range envelopes, every pound saved and percentage of drag reduced mattered. The requirement to replenish combat unit losses quickly by minimizing production timelines also discouraged the application of camouflaged paint schemes during this time.

Approaching D-Day in 1944, and consistent with the trend away from emphasizing camouflage as air superiority was gained and offensive operations increased, Allied fighters and bombers adopted standardized Allied Expeditionary Air Force (A.E.A.F.) “invasion stripes” on wings and fuselages to aid ground units with friendly identification. American P-47s and P-51s (which debuted in September, 1943) participating in D-Day contained the A.E.A.F. stripes, and while some debuted in 1942 and 1943 with olive drab upper surfaces and gray lower surfaces, most new arrivals after 1944 sported bare metal finishes. P-38s also wore the olive drab and gray scheme, as did several American transports.[138]

[136] Whistler, 10.
[137] Major Daniel S. Konyha and Major Robert M. Brown, “MAC Project 1-48-81: TEMPORARY CAMOUFLAGE PAINT (TCP) FINAL REPORT,” 1984.
[138] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 146.

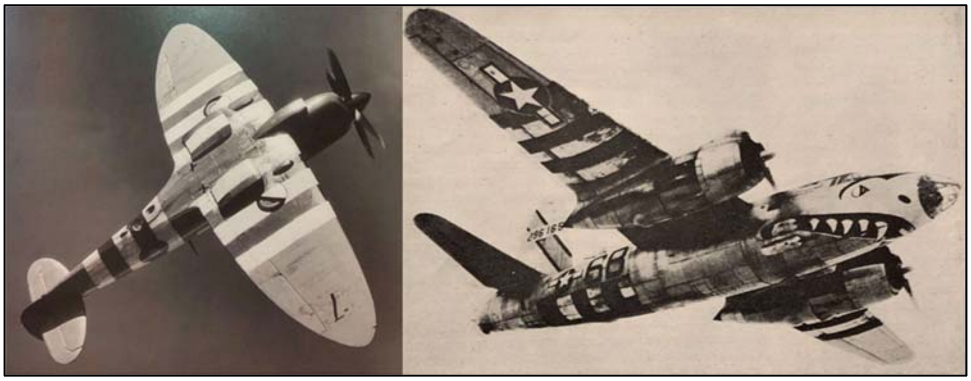

Figure 19: Spitfire & Marauder in A.E.A.F. Invasion Stripes, 1944
Source: Adapted from Martin J. Dougherty, Camouflage at War: An Illustrated Guide from 1914 to the Present Day (New York, NY: CHARTWELL BOOKS, 2017), 137 (left) and Bruce Robertson, Aircraft Camouflage and Markings 1907-1954, ed. D. A. Russell (Harleyford, Marlow, Bucks, England: Harleyford Publications Limited, 1956), 144 (right).

Post-WWII: 1945-1960s

As WWII ramped down, wartime camouflages were being discarded in exchange for pre-war silver or aluminum-colored finishes.[139] The focus on aircraft camouflage, however, reemerged with the start of the Cold War. Applying camouflage paint schemes to jets capable of supersonic flight required smooth finishes, both to ensure maximum aerodynamic performance and to "prevent the very paint from being torn from the surfaces at high speeds."[140] Smooth finishes would be a mainstay of the supersonic jet age, which was ushered in by the Korean War. Most day fighters and fighter-bombers flown in the Korean War utilized natural metal finishes. Although radar and electronic identification capabilities were advancing, the technologies had not yet been perfected, and many jet fighters of this era were of similar size and shape. US F-86s and Korean MiG-15s, for example, looked very similar, especially at the

[139] Robertson, 162.
[140] Robertson, 162.

increased speeds realized in the jet age.[141] Since these similarities meant differentiating between friend and foe was still a challenge, each nation implemented unique, overt marking systems on the wings and fuselages of aircraft. Most bombers and reconnaissance aircraft, however, continued the tradition of more covert paint schemes. Some American night bombers, such as the B-26, were painted gloss black. Others, however, such as the nuclear-capable B-36s and B-52s, were painted with "anti-atom" white finishes on the undersides to protect against potential thermal radiation from nuclear blasts.[142]

Federal Standard 595 (FED-STD-595), adopted in 1956, governed modern aircraft paint colors until it was superseded by Aerospace Material Specification-595A (AMS-STD-595A).[143] Both FED-STD-595 and AMS-STD-595A utilize a five-digit coding system to identify each color.[144] The first digit indicates the level of gloss or sheen (1 = glossy; 2 = semi-gloss; 3 = flat/lusterless), the second "indicates the major color group to which a given shade belongs," (0 = brown; 1 = red; 2 = orange; 3 = yellow; 4 = green; 5 = blue; 6= grey; 7 = other: white/black/violet/metallic; 8 = fluorescent) and the "last three digits are peculiar to a specific color."[145] In general, the last three digits indicate intensity, with lower values indicating darker colors, and higher values indicating lighter colors.[146]

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141 Doug Dildy and Warren Thompson, *F-86 Sabre vs MiG-15: Korea 1950-53*, illustrate (Long Island City, NY: Bloomsbury Publishing, 2013).
142 "AIRCRAFT INTELLIGENCE: U.S.A.," *FLIGHT*, November 1955, 741.
143 "AMS STANDARD 595A COLOR: Standard Colors Used in U.S. Government Procurement," US Government General Services Administration, 2014, http://ams-std-595-color.com.
144 Whistler, "United States Air Force Camouflage 1933-1969," 10–13.
145 Whistler, 10.
146 "Federal Standard 595 Paint Spec Information," n.d., http://www.dot.state.oh.us/Divisions/Engineering/Structures/News Document/Federal Standard 595 Paint Spec.pdf.

Figure 20: Example of Current AMS-STD-595A Color Standard
Source: "AMS STANDARD 595A COLOR: Standard Colors Used in U.S. Government Procurement," US Government General Services Administration, 2014, http://ams-std-595-color.com.

In March 1966, the USAF released Technical Order (T.O.) 1-1-4, EXTERIOR FINISHES, INSIGNIA AND MARKINGS APPLICABLE TO AIRCRAFT AND MISSILES.[147] In an apparent shift from the relatively permissive Korean War mentality to a focus on a NATO and Vietnam mindset, this document "once again called for [readopting] camouflage painting on USAF aircraft," but was "prompted primarily by attacks against air bases" rather than WVR deception purposes.[148] Just as the British had standardized aircraft camouflage patterns and paint schemes in the 1940s, the Engineering Data Section of Warner Robins Air Materiel Area determined camouflage paint schemes for USAF aircraft, and 34 approved patterns were incorporated into T.O. 1-1-4 in 1966.[149] A majority of these camouflage schemes employed a mix of dark green/shadow green (34079), olive drab green/medium green (34102),

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[147] "T.O. 1-1-4: EXTERIOR FINISHES, INSIGNIA AND MARKINGS APPLICABLE TO AIRCRAFT AND MISSILES," 1964, https://www.usaf-sig.org/index.php/reference/111-color-information/401-technical-order-t-o-1-1-4-1964.
[148] Whistler, "United States Air Force Camouflage 1933-1969," 13.
[149] Whistler, 13.

and tan/desert tan (30219) topsides, with gray (36622) undersides.[150] Commonly referred to as the Southeast Asia or SEA scheme, these standardized patterns covered most USAF combat aircraft throughout the Vietnam War and into the mid-1970s.[151]

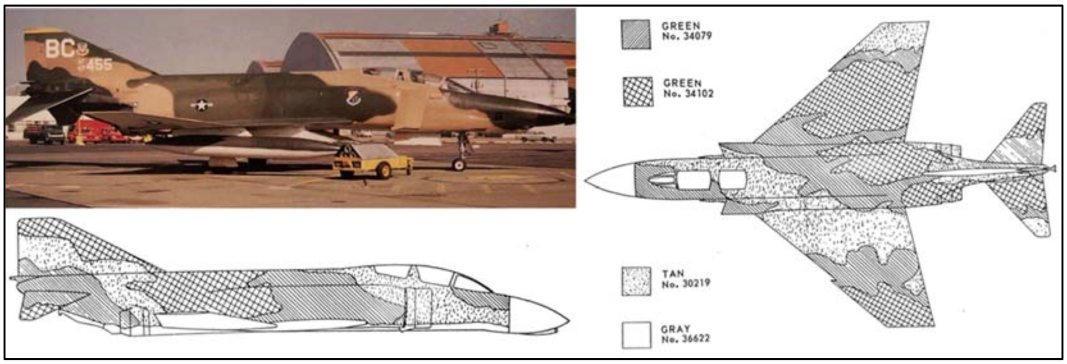

Figure 21: F-4 in Southeast Asia Camouflage Pattern, 1971
Source: Adapted from Patrick Martin, Tail Code: The Complete History of USAF Tactical Aircraft Tail Code Markings (Atglen, PA: Schiffer Publishing Ltd., 1994), 88 and 240.

1970s-Modern Era

As the conflict in Vietnam wound down, and the USAF shifted focus back to the European theater, the Southeast Asia paint scheme was eventually replaced by the European One paint scheme in the mid-1970s. The European One camouflage scheme consisted of two shades of green (34092 and 34102) and charcoal (36118) arranged in full wrap-around form.[152] Later, a modified European One paint scheme was developed that replaced the charcoal with a dark gray (36081) color.[153] This new camouflage pattern was tested and employed on the USAF A-10 Thunderbolt, a close-air-support attack aircraft, some dual-role fighters

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[150] Whistler, 13.
[151] Patrick Martin, *Tail Code: The Complete History of USAF Tactical Aircraft Tail Code Markings* (Atglen, PA: Schiffer Publishing Ltd., 1994), 8.
[152] Martin, 9.
[153] Barry C. Wheeler, *An Illustrated Guide to Aircraft Markings* (New York, NY: Prentice Hall Press, 1986), 134.

such as the F-4 Phantom, as well as several large transport aircraft such as the C-5A/B Galaxy and C-141 Starlifter.[154] The high-flying air superiority fighters, however, chose a slightly different approach.

A series of experiments in the mid-1970s by the United Kingdom's Royal Aircraft Establishment proved that an aircraft "painted overall matte light grey was more difficult to see against the sky than one with a multicolored disruptive scheme."[155] Both the USAF and USN conducted camouflage trials in the 1970s, eventually reaching a similar conclusion as the UK's Royal Aircraft Establishment: a counter-shaded pattern of two grays was more effective at medium-to-high altitudes than multicolored camouflage schemes in most air superiority-type fighters.[156] Based on these tests, "grey in various shades has been generally accepted as the most effective color for fighter aircraft" in Western air forces.[157] The USAF and USN decided to apply two shades of gray to its F-15C Eagle and F-14 Tomcat aircraft, respectively, and this color scheme still exists on each service's modern air superiority fighters (USAF's F-22 Raptor, F-15C Eagle, and F-16 Fighting Falcon variants, as well as all variants of the USN's F-18 Hornet).[158] While specific details of current aircraft coverings are classified, it has been acknowledged that F-16 paint schemes of the late 1980s employed a "special camouflage coating" that is "highly infrared reflective and diffuses sunlight, thus helping the aircraft blend more easily into the background" at longer ranges.[159]

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[154] Wheeler, 134–35.
[155] Wheeler, 124.
[156] Wheeler, 126.
[157] Wheeler, 124.
[158] Wheeler, 126–29.
[159] J. Jones, *Stealth Technology: The Art of Black Magic*, ed. Matt Thurber (Blue Ridge Summit, PA: TAB BOOKS Inc., 1989), 31.

The US' current MIL-STD-2161C, PAINT SCHEMES AND EXTERIOR MARKINGS FOR U.S. NAVY AND MARINE CORPS AIRCRAFT, states that "tactical paint scheme patterns are based on optical principles that dictate certain nonreflective colors, color configurations, and color proportions."[160] As part of MAC Project 1-48-81 (discussed further below), the Air Force Wright Aeronautical Laboratories (AFWAL) Avionics Laboratory informed MAC leaders that "reflectance differences [between two or more colors] greater than five percent are perceptible and increase contrast."[161] AFWAL also advised that "color seldom plays an important part in determining detection range," which is "due to the atmosphere 'washing out' color over a fairly short range and also that we are color blind for small objects, which is what an airplane appears to be at long ranges."[162]

Visual reflectance is not the only concern, however. As part of MAC Project 1-48-81, AFWAL also found that "some colors exhibit higher IR reflectance" values than others, based on the pigment used.[163] The study found that, in general, brown colors have higher IR reflectance values than gray colors, and for this reason, solid or varying shades of gray were recommended.[164] Interestingly, while this finding countered traditional thinking on camouflage usage on the land domain, where "good colors such as brown or gray-green" tend to dominate color scheme

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160 Naval Air Systems Command, *MIL-STD-2161C(AS): PAINT SCHEMES AND EXTERIOR MARKINGS FOR U.S. NAVY AND MARINE CORPS AIRCRAFT* (Department of Defense, 2014), 8.
161 Konyha and Brown, "MAC Project 1-48-81: TEMPORARY CAMOUFLAGE PAINT (TCP) FINAL REPORT," B-2.
162 Konyha and Brown, B-2.
163 Konyha and Brown, B-2.
164 Konyha and Brown, B-2, B-3.

patterns, it did align with the 1970s findings of the Royal Aircraft Establishment.[165]

US aviation artist Keith Ferris was a strong advocate for the shift to counter-shaded "all-gray" paint schemes by US air forces. In the late 1970s, Ferris had been instrumental in convincing the USAF and USN to eliminate the red, white, and blue colors from the national insignia on most combat aircraft.[166] Ferris also filed several patents that combined a counter-shaded, asymmetrical, blocked-type camouflage pattern[167] using multiple shades of gray, typically matte dark gray (36118), dark gull gray (36231), and light gull gray (36440).[168] These ideas and patents included painting fake canopies or tail shadows on the undersides of aircraft to resemble features on the top.[169] Ferris believed it was "important to avoid symmetrical camouflage patterns…the whole idea is to deceive the eye, so that even when an enemy catches sight of you, he never can be sure what part of you he's looking at or how your plane is oriented in the sky."[170] Ferris' ideas were tested, but not permanently implemented, by US F-4s, F-14s,[171] and F-15s,[172] and some were later adopted by foreign countries.

165 Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 63.
166 Malcolm W. Browne, "Air Force Sees Beauty in Ugly Ducklings," *The New York Times (Archives)*, August 18, 1987.
167 Carlisle Keith Ferris, CAMOUFLAGED AIRCRAFT, SURFACE VESSEL PR VEHICLE OR THE LIKE, Patent No. 4,089,491 (United States of America, issued 1976).
168 Robert J. Archer, *United States Military Aviation: The Air Force* (Leicester, England: Midland Counties Publications, 1980), 66.
169 Carlisle K. Ferris, CAMOUFLAGED AIRCRAFT, Patent No. 4,611,524 (United States of America, issued 1980).
170 Browne, "Air Force Sees Beauty in Ugly Ducklings."
171 Wheeler, *An Illustrated Guide to Aircraft Markings*, 152–53.
172 Archer, *United States Military Aviation: The Air Force*, 195.

Figure 22: Ferris Design Scheme for F-4 & F-15
Source: Adapted from "F-4, F-14 and F-15 Ferris Schemes," Aviation Archives, 2015, http://aviationarchives.blogspot.com/2015/04/f-4-f-14-and-f-15-ferris-schemes.html.

USAF Aggressor squadrons, which replicate adversary aircraft and tactics, have tested some of these Ferris designs throughout their history,[173] and continue to replicate adversary paint schemes to this day, allowing aviators from the US and its allies to prepare for combat in large-scale training exercises.[174]

USAF Camouflage Testing: Optimizing Modern Aircraft Camouflage?

Since the late 1960s, several modern aircraft paint schemes have been determined or updated by the Operational Test and Evaluation process. Two examples, MAC Project 1-48-81, which explored the application of temporary camouflage paint, and TAC Project 85G-061F, which explored paint schemes for the F-15E Strike Eagle, are included below.

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[173] Bert Kinzey and Ray Leader, *Colors & Markings of USAF Aggressor Squadrons*, First (Blue Ridge Summit, PA: TAB BOOKS Inc., 1988), 35.
[174] Kinzey and Leader, 35.

MAC Project 1-48-81, Operational Test and Evaluation TEMPORARY CAMOUFLAGE PAINT (TCP) was published in February 1981, and tested various aspects of temporary camouflage paint. It found that approximately 22 gallons of paint were used to spray on the temporary camouflage paint, and this added between 165 and 176 pounds to the weight of the airframe.[175] This test ultimately recommended that the concept of applying TCP over existing paint schemes should be abandoned, and instead, the "European One"[176] camouflage scheme should be permanently applied to aircraft designated for combat operations.[177]

Figure 23: F-4 in European One Camouflage Scheme, 1980s
Source: Bert Kinzey, Colors & Markings of the F-4D Phantom II (Blue Ridge Summit, PA: TAB BOOKS Inc., 1986), 59.

In 1985, Headquarters (HQ) Tactical Air Command (TAC) directed the USAF Tactical Fighter Weapons Center to test possible patterns and paint schemes for its new F-15E fighter. The aircraft was designed originally as a dual-role, air superiority and ground attack, strike fighter, and therefore the project's goal was to determine which paint scheme best limited an adversary's ability to acquire the F-15E from both the

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[175] Konyha and Brown, "MAC Project 1-48-81: TEMPORARY CAMOUFLAGE PAINT (TCP) FINAL REPORT," 22.
[176] Wheeler, *An Illustrated Guide to Aircraft Markings*, 134–35.
[177] Konyha and Brown, "MAC Project 1-48-81: TEMPORARY CAMOUFLAGE PAINT (TCP) FINAL REPORT," 25.

ground and air. Three candidate camouflage schemes were provided by HQ TAC and the F-15 Systems Program Office. "The Nightfighter (NF) was a solid dark grey (36118). The Mod Eagle (ME) was a dark [grey] (36176) top and light grey (36251) bottom mix. The Visual Signature Reduction (VSR) was a four-color combination of dark grey (36118), medium grey (36287), light grey (36307), and tan (36375).

Figure 24: Visual Signature Reduction F-15E Test Paint Scheme
Source: Patrick Martin, Tail Code: The Complete History of USAF Tactical Aircraft Tail Code Markings (Atglen, PA: Schiffer Publishing Ltd., 1994), 148.

A fourth F-15C with a Standard (STD) paint scheme (36320 and 36375) was flown with the candidate aircraft."[178] The four test candidate patterns were flown against both ground and air observers in "various formations/engagements against all available look-up and look-down backgrounds."[179]

The report's conclusions highlight (unintentionally) the inherent difficulty of determining "optimum camouflage" across a varied operating environment. While the NF scheme was found to be the most effective in a look-down or low-altitude environment, the ME was the most difficult

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[178] Capt Chris G. Goetsch, "(U) TAC Project 85G-061F: F-15E Camouflage Evaluation" (Nellis AFB, NV, 1986), v.
[179] Goetsch, v.

to acquire at high altitudes or look-up environments. Though not an original objective of the test, the STD paint scheme used by F-15Cs of the mid-1980s was found to be "inferior to the ME paint scheme in all environments, and to the NF paint scheme in most environments."[180] The report officially recommended that HQ TAC should "paint the F-15E with the NF camouflage paint scheme on upper surfaces and the underside of the ME paint scheme on lower surfaces."[181] Ultimately, the F-15E was painted in the NF scheme overall, and the recommendations for the F-15C were not implemented.

Besides this author's personal affinity for the F-15E, other factors make this an interesting case study in the development of aircraft camouflage. At the time of the test, no F-15E had yet been officially produced. A modified version of a two-seat F-15B had won a USAF selection competition for a new fighter against the F-16XL in 1984; a production F-15E first flew in 1987, and the F-15E was declared combat-ready in 1989, having reached initial operational capability in September of that year with the 336th Tactical Fighter Squadron at Seymour Johnson AFB, NC.[182] In describing the F-15E operational concept, the camouflage test team assessed that "although the F-15E will retain the inherent F-15 [air-to-air] capability, it will be optimized for the deep interdiction mission using nuclear and conventional ordnance. While the F-15E may ingress at medium or high altitude to extend its range, the low-altitude combat arena will be its primary operating environment."[183] Notably absent from that assessment is any assumption about whether a

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[180] Goetsch, 9.
[181] Goetsch, 9.
[182] James R. Ciborski, "The F-15 Eagle: A Chronology," Wright-Patterson AFB History Office, 2002, https://web.archive.org/web/20070920040909/http://www.ascho.wpafb.af.mil/AFtopics/f15chronology.htm.
[183] Goetsch, "(U) TAC Project 85G-061F: F-15E Camouflage Evaluation," 1.

deep interdiction mission would be more likely to take place at night or during daylight hours, which, if known, could have assisted in optimizing the result and possibly changed the test report's conclusions. To be fair, the USAF concept of "owning the night" may not have yet been well established in the mid-1980s.

In priority order, the criteria used for selection of the best F-15E camouflage scheme were:

1. Reduce the initial air-to-air/surface-to-air visual acquisition range in the low-altitude environment.
2. Reduce the range at which an air-to-air observer can visually differentiate between an F-15E and an air-superiority F-15.
3. Reduce the initial air-to-air/surface-to-air visual acquisition range in the medium- and high-altitude environments.[184]

To assess measures of effectiveness, the project compared the "mean initial acquisition range, the mean visual ID range, and a test team subjective evaluation of paint scheme effectiveness." While the first two measures of effectiveness seem objective in nature, a real-world failure of distance-measuring equipment in the test airspace prevented accurate acquisition and ID range determinations.[185] This resulted in all ranges being estimated, or ranked in relative fashion to one another. Though the "relative to one another" method might seem reasonable, it was discovered during the test that order of identification was largely determined by formation position of the test candidates. The final measure of effectiveness is equally problematic, based on its acknowledged subjectivity. During the test, the only objective measurement gathered involved known reflectance values of the various paints used. Without the technology available to perform precise

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[184] Goetsch, 4.
[185] Goetsch, 5.

instrumentation or data analysis, definitive conclusions will be difficult to justify.

Both the criteria list and the chosen measures of effectiveness point to additional questions concerning the test assumptions. The highest priority factor seems to make sense, given the team's understanding of the proposed operational concept. The emphasis on visual acquisition range in the low-altitude environment, however, may no longer be valid. Given the proliferation of modern threat systems and improved capabilities of surface-to-air missiles and anti-aircraft artillery, the low altitude regime is more dangerous than it was in previous decades. If forced to fly low, a modern F-15E would likely employ its automatic terrain-following radar system at night, or utilize terrain-masking techniques if flying during the day. In either case, only the top of the jet would need to blend in with the ground. At the airspeed flown by an F-15E low-altitude, a ground observer manning any visually-guided threat system would likely be unable to adjust in time.

The second priority factor concerning ID differentiation range generates a most puzzling question: why was it important to be able to distinguish between the various models of F-15? In the mid-1980s, electronic methods of detection and identification were widely used. The F-15E also planned to carry the same air-to-air loadout as the air superiority F-15s, meaning the main reason for wanting to differentiate between F-15 types would involve understanding the differences in aircraft performance in the visual maneuvering (or "dogfighting") arena. If two aircraft make it to a merge and begin dogfighting, they are likely close enough to identify the other aircraft type and execute an appropriate game plan. Additionally, when aircraft are approaching one another, the tally gained by an aware pilot during the beyond-visual-range (BVR) to WVR transition typically begins as recognized movement of a dark spot, transitions to a general jet-shaped outline, and, gradually, distinguishing features (such as one or two vertical or slanted tails, high- or low-mounted wings, blended or bubble canopy shapes, and weapons or fuel tanks) become recognizable. During the test, observers were unable to differentiate between paint scheme types when candidates flew alone, and as mentioned, "determined that formation position drove the results" when test candidates flew together.[186] Adding to the oddity of this criteria, one advantage of a dual-role fighter, in theory, is that an adversary will be unable to differentiate between one in a dedicated air-to-air or air-to-ground role. Perhaps this modern-day assumption did not apply in the USAF of the mid-1980s.

Some of the previous discussion about gaining a long-range tally and electronic detection and identification methods also apply to the 1986 test's last priority criteria of reducing medium- or high-altitude visual acquisition. When seeking a long-range tally, pilots generally look for movement relative to the background environment. If all paint schemes appear as a black dot or speck at long range, then the general concept first developed in 1918 about lighter under surfaces and darker upper surfaces should still be valid. Additionally, it is a reality that most modern combat aircraft employ in the medium-to high altitude regime. Although reducing visual acquisition at higher altitudes was the last priority in 1986, this would likely be the top priority in a similar camouflage test performed today. While precise distance measuring equipment was not available, the test team was able to estimate acquisition range for the surface-to-air observer portion of the test. At low altitude (1,000 feet above ground level), the NF scheme was acquired at 10.0 nautical miles (nm) from the target (observer) location, while the

[186] Goetsch, 6.

STD, ME, and VSR schemes were acquired at 11.0 nm, 12.0 nm, and 12.0 nm, respectively. At medium altitude (5,000 feet AGL), the ME and VSR schemes were spotted last, both at approximately 3.0 nm from the target, while the STD and NF schemes were spotted at 4.5 nm and 7.0 nm, respectively. The high-altitude (10,000 feet AGL) test produced the greatest variation in acquisition ranges: the ME scheme was not acquired until 1.5 nm from the target, the VSR and STD schemes were both spotted at 4.0 nm, while the NF scheme was acquired at 7.0 nm from the target.[187] The 4.0 nm and 5.5 nm differences on the medium- and high-altitude tests between the ME and NF schemes should be enough to give pause to the interested reader, especially considering the implications for modern threat environments. Additional concerns arise when examining what was considered "medium- and high-altitude" for the purposes of this test. Although it is not specified, it is likely based on limitations of the air-to-ground ordnance that existed during that period. The final question generated here, then, is: why did HQ TAC not implement the report's recommended paint scheme on either the F-15E or the air superiority F-15s?[188] Other countries, such as Israel and Saudi Arabia seem to have adopted the report's recommendation of an upper/lower camouflage mix.

[187] Goetsch, 7.
[188] The "air superiority" F-15s are the F-15A/B/C/D models. These models have solely an air-to-air mission.

Figure 25: Israeli F-15s with Upper/Lower Camouflage Mix
Source: TSGT KEVIN J. GRUENWALD, USAF - http://www.dodmedia.osd.mil/Assets/Still/2007/Air_Force/DF-SD-07-08323.JPEG, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2155384 .

Unfortunately for US F-15E crews, this answer remains elusive. While attempting to delay an enemy's initial detection as long as possible is still a valid objective, it is important to note that paint schemes are merely one aspect of aerial CC&D that applies. To maximize the effectiveness of aerial CC&D, more than visual camouflage is needed. The next chapter addresses other considerations for influencing visual perception in air warfare, and discusses the implications of CC&D on WVR maneuvering.

Chapter 2

Influencing Visual Perception in WVR Maneuvering

He who hesitates is lost.

Anonymous Fighter Pilot Proverb

Camouflage doctrine has evolved two main functions, which can be categorized as either simulation or dissimulation. Simulation involves dummy or decoy military objects that are displayed to mislead the enemy, whereas dissimulation involves concealing military objects to mask or hide reality.[189] Deception is used to mask intention, place, time, strength, and style of attack.[190] Throughout the history of air warfare, all forms of camouflage, concealment, and deception have been employed to varying degrees. As shown above, many of these forms of deception throughout the historical progression of aerial CC&D have been adapted from nature, or developed by experts from fields not traditionally associated with the military. The following sections address additional lessons learned from the natural world, as well as other methods of reducing an aircraft's visual signature.

More Lessons from Nature

In the natural world, camouflage is a survival mechanism. It is therefore logical that lessons from the study of nature would influence military tacticians. Camouflage's mission in warfare is to conceal, confuse, or mislead.[191] As previously mentioned, Thayer, Kerr, Cott, and other naturalists documented many applicable CC&D lessons from the

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[189] Barton Whaley, *Stratagem: Deception and Surprise in War*, *International Studies* (Norwood, MA: Artech House, 2007), 8.
[190] Whaley, *Stratagem: Deception and Surprise in War*. 112.
[191] Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 6.

study of nature. Early studies noted that "chameleons, shrimps, and squids can change color to match their surroundings."[192] Since its discovery, this form of adaptive camouflage has intrigued scientists and camouflage specialists alike. Scientists studying the adaptive camouflage capabilities of both octopus and cuttlefish have determined there are three general camouflage pattern types found in nature: uniform, mottled, and disruptive.[193]

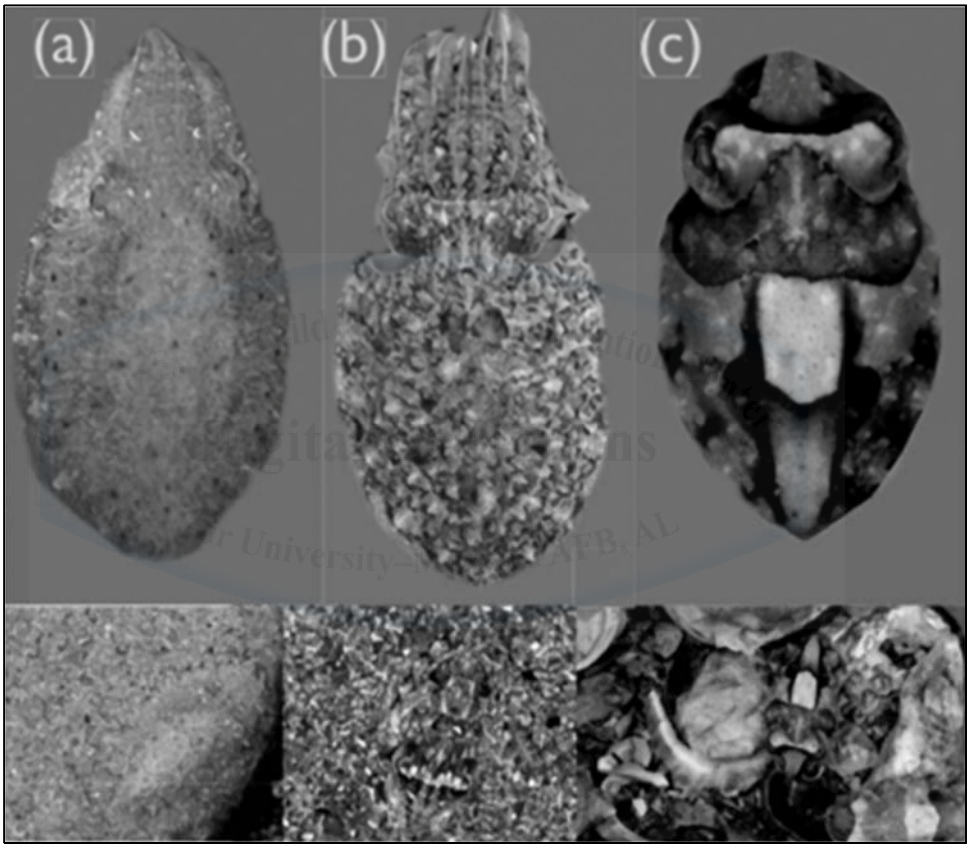

Figure 26: Three General Camouflage Patterns Found in Nature – Uniform (a), Mottled (b), and Disruptive (c)
Source: Adapted from Roger T. Hanlon et al., "Rapid Adaptive Camouflage in Cephalopods," 2011, 146, https://www.researchgate.net/publication/283874370.

[192] Reit, 5.
[193] Roger T. Hanlon et al., "Rapid Adaptive Camouflage in Cephalopods," 2011, 146, https://doi.org/10.1017/CBO9780511852053.009.

Other Methods of Visual Signature Reduction

In addition to using camouflage colors to blend into a background scene, there is also the very basic idea that decreasing the size of an object makes it more difficult to see. When approaching the limits of visual range, there are two basic ways to do this: one involves a decrease in overall aircraft size, and one involves minimizing planform. Put another way, minimizing the cross-sectional area of an aircraft relative to an enemy minimizes an adversary's ability to gain a tally at longer ranges. In most cases, and in very simple terms, this involves keeping the pointy-end pointed towards the enemy. In modern flying terminology, planform can be described in degrees of antenna-train-angle (ATA), which is measured in degrees off an aircraft's nose.[194] A fighter that is pointed directly at another aircraft is showing 0° ATA (also known as pure pursuit), while one that is flying alongside and parallel with another aircraft is showing 90° ATA.

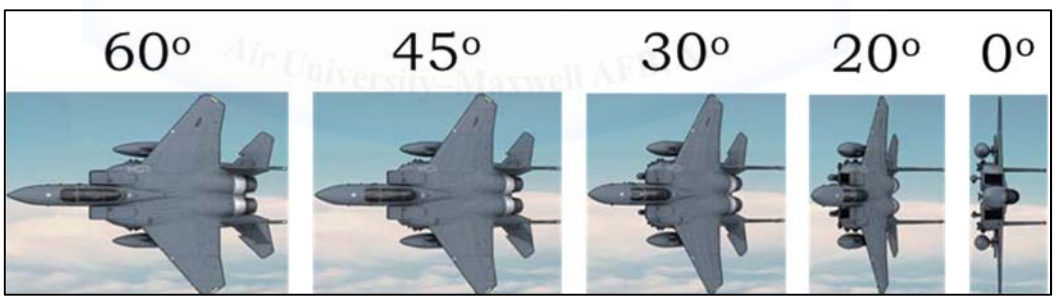

Figure 27: Visual Signature Management – Planform (60° ATA) vs. Pure Pursuit (0° ATA)
Source: Adapted from AFTTP 3-3.F-15E, (U) COMBAT AIRCRAFT FUNDAMENTALS -- F-15E (USAF ACC/A3, 2014), 4–62, https://intelshare.intelink.gov/sites/561jts/3-3/default.aspx.

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[194] AFTTP 3-3.F-15E, *(U) COMBAT AIRCRAFT FUNDAMENTALS -- F-15E* (USAF ACC/A3, 2014), 4–13, https://intelshare.intelink.gov/sites/561jts/3-3/default.aspx.

Although this paper does not address beyond-visual-range CC&D considerations, an early lesson learned in the development of the F-117 is that shape matters greatly in stealth aircraft designs.[195] Advantage can also be gained, however, by applying the same concept in the WVR arena. By combining decreased planform (or ATA) with physically smaller airframes, it is possible to delay an enemy's visual acquisition. Examples of the effects of planform and size can be seen when comparing the frontal aspects across a historical progression of US fighters.

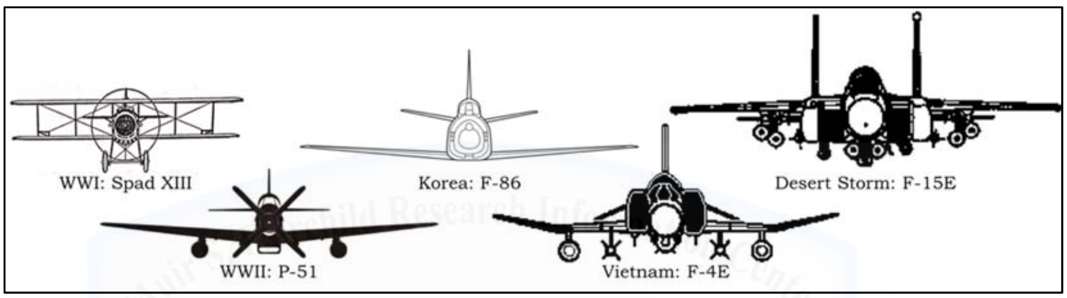

Figure 28: Front View of Aircraft Flown in WWI, WWII, Korea, Vietnam, & Desert Storm
Source: Author's original compilation of open-source photos (to scale)

Examining the frontal aspect outlines of the aircraft below show how this idea has been implemented even in modern advancements from 4th- to 5th-Generation aircraft.

[195] Jones, *Stealth Technology: The Art of Black Magic*, 28–32.

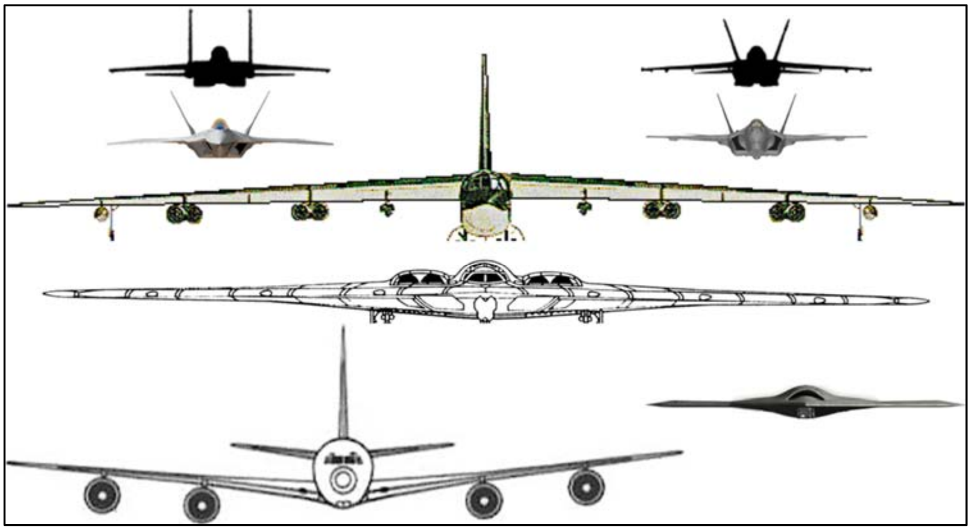

Figure 29: Comparing Frontal Aspects of 4th- and 5th-Gen US Aircraft (F-15C with F-22, B-52 with B-2, the USN's F/A-18E/F with F-35C, & KC-135 with X-47B)
Source: Author's original compilation of open-source photos (to scale)

Besides using specific paint schemes or immaculate materials and shapes in the construction of aircraft, there are some other ways to prevent an enemy aircraft from gaining a tally. In the earliest days of air warfare, pilots quickly learned to keep the sun at their back, making themselves extremely difficult for enemy eyeballs to detect. While it is not always possible to control the position of the sun relative to the position of opposing sides in an aerial battle, the idea of exploiting environmental conditions is still taught to all fighter pilots, and is the most basic form of aerial CC&D.

Other technological solutions have been developed to reinforce the concept of manipulating visual detection. Yehudi lights are one such example. First installed on the leading edges and frontal fuselage areas of U-boat hunting B-24 Liberators, Yehudi lights were designed to employ counter-illumination, matching an aircraft's visual signature with the illumination levels of the background environment.[196] This allowed a B-24 to approach within striking range before it was spotted by the enemy's periscope and the U-boat disappeared beneath the waters.

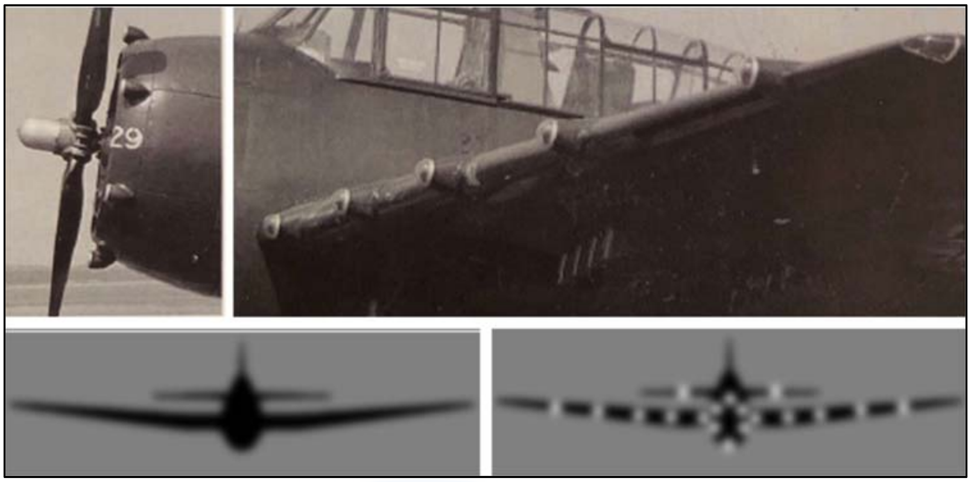

Figure 30: Yehudi Lights – Counter-illumination as Camouflage
Source: Adapted from Martin J. Dougherty, Camouflage at War: An Illustrated Guide from 1914 to the Present Day (New York, NY: CHARTWELL BOOKS, 2017), 138 and "File:Principle of Yehudi Lights with Avenger Head-on View.Jpg," Wikimedia Commons, the free media repository, accessed April 13, 2019, https://commons.wikimedia.org/w/index.php?title=File:Principle_of_Yehudi_Lights_with_Avenger_head-on_view.jpg&oldid=263082698.

Once an adversary has approached to within visual range, another option of manipulating perception is to actively disrupt an enemy's vision via a laser or IR dazzler, or some type of disorienting, high-intensity strobe-type light. While this approach may present Law of Armed Conflict concerns for US forces, modern enemy ground systems already exist that possess similar capabilities. An octopus or squid that releases a cloud of ink to escape a perceived threat is an example of this phenomenon that can be found in nature. The goal here would be to attack the observe-orient phases of an enemy's observe-orient-decide-act

[196] Dougherty, *Camouflage at War: An Illustrated Guide from 1914 to the Present Day*, 138.

(OODA) decision cycle. Momentarily "blinding" an adversary could either help a defender avoid or escape a disadvantageous situation, or serve as a pre-emptive offensive enabler for an attacker.

Another aspect of an aircraft's coating that must be considered is glint, which is a small flash of light reflected off a surface. Here a tradeoff between aerodynamics and susceptibility to an adversary's visual lookout must be considered. A smooth, shiny, or glossy surface, while more aerodynamic than a rough, dull surface, exhibits higher levels of glint. The more glint reflected off an aircraft, the greater a pilot's ability to detect an adversary at the limits of visual range.[197] During WWII, for example, pilots could recognize glint reflecting off parked aircraft from more than forty miles out over the sea.[198] This tradeoff led aircraft designers and engineers to develop smooth, flat (not shiny) paints, as well as special anti-reflective coatings for the glass canopies of most modern fighter aircraft.[199] Interestingly, the night bombers of WWII alternately experimented with both flat and shiny black paint based on the glint phenomenon. Researchers found that while flat black exhibited less glint from ground searchlights at night, it did not blend in as well with the darkness of the night sky behind it, leaving what appeared to be dark gray bombers silhouetted against a black sky. Shiny black paint, however, blended in better with the sky behind it, and while the glossy finish concentrated the flashes of light when hit with searchlights, it improved the survival rates during night bomber raids. Because the shiny black bombers blended better into the background, it was more

[197] Wheeler, *An Illustrated Guide to Aircraft Markings*, 130.
[198] Robertson, *Aircraft Camouflage and Markings 1907-1954*, 137.
[199] The US Army also experimented in the 1970s with reduced glare canopies for its helicopters. Source: MAJ Gilberto Marrero-Camacho and MAJ Richard B. McDermott, "(U) MASSTER Test Number FM 153: Camouflage Evaluation Report (Phase I)" (Fort Hood, Texas, 1974).

difficult for ground anti-aircraft artillery units to determine the overall shape, direction, and speed of the bombers. In many cases, although the momentary flashes of glint were easily seen, the "bright but small reflections at several points on the aircraft…may go entirely unnoticed by ground observers when the aircraft is at altitude."[200]

The MAC Project study also proposed that while "color may have utility for the parked aircraft case…for the case of airborne aircraft it is a questionable value."[201] Though not explicitly stated, AFWAL's subjective conclusion assumes that because "we are color blind for small objects," and because "the atmosphere washes out color over a fairly short range," WVR visual camouflage has little utility.[202] While this conclusion may be valid from a strictly engineering or scientific perspective, from a pilot's perspective, visual camouflage does matter. Examining basic fighter maneuver (BFM) principles and understanding how visual deception methods influence a pilot's observe-orient-act-decide decision cycle (commonly referred to as the "OODA Loop") will reinforce this point of contention.

How Camouflage Affects Basic Fighter Maneuver Fundamentals

> *Machines don't fight wars. Terrain doesn't fight wars. Humans fight wars. You must get into the minds of humans. That's where the battles are won.*
>
> John Boyd, in *The Mind of War*

In the late twentieth century, Colonel John Boyd developed a theory about how to impose paralysis on an enemy, and created an

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[200] Whistler, "United States Air Force Camouflage 1933-1969," 8.
[201] Konyha and Brown, "MAC Project 1-48-81: TEMPORARY CAMOUFLAGE PAINT (TCP) FINAL REPORT," B-3.
[202] Konyha and Brown, B-2.

“observe-orient-decide-act” cyclical model he coined the “OODA Loop.”[203] Boyd’s OODA Loop recognized that, for two pilots in an aerial engagement, a tactical advantage could be realized by the one who progressed through the OODA Loop cycle more efficiently.[204] Relating to air warfare, the pilot who took an action, and then progressed through the OODA cycle again to take another action before the opponent was able to respond (orient-decide-act) to the initial action, could impose their will on an enemy. The usage of CC&D in air warfare applies directly to the OODA Loop concept by first delaying an opponent’s ability to accurately “observe,” then by confounding the ability to “orient,” both of which lead to inaccurate “decisions” or ineffective “actions.”

Boyd also led the creation of Energy-Maneuverability (EM) diagrams for US fighters that could be used to compare relative strengths and weaknesses between two aircraft.[205] Using data collected during flight testing, Boyd’s EM diagrams allowed the examination of rate and radius for fighter aircraft at various altitudes, airspeeds, and configurations. These rate and radius diagrams can be used to compare the performance envelopes of different aircraft. Along with learning basic fighter maneuver fundamentals, modern USAF fighter pilots are taught these EM diagrams as a way to understand the optimum airspeed and altitude regimes where one type of aircraft may enjoy a performance advantage over another. Part of this learned understanding involves maximizing aircraft flight performance in one of several ways. Two of

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[203] Robert Coram, *Boyd: The Fighter Pilot Who Changed the Art of War* (New York, NY: Bay Back Books / Little, Brown and Company, 2002), 334–36.
[204] Coram, 327–28.
[205] Grant T. Hammond, *The Mind of War: John Boyd and American Security* (Washington, DC: Smithsonian Books, 2001), 57.

these ways are characterized in terms of aircraft turn performance: turn rate and turn radius.

Each of these performance measures can be visualized by imagining an aircraft performing a level turn in the sky. If a trail is drawn behind that aircraft, a level turn traces a circular shape. Turn radius is simply that: the radius of that imaginary circle traced in the sky, which is generally measured in feet. Turn rate is measured by calculating the degrees turned over a given amount of time, and is usually measured in degrees per second. Aircraft performance during BFM (or any WVR aerial maneuvering) is also thought of in terms of kinetic energy (higher airspeed = higher kinetic energy) or potential energy (higher altitude = higher potential energy).[206] In accordance with one of the "Golden Rules of BFM," pilots must trade energy for nose position wisely. Here a tradeoff exists between maximizing instantaneous versus sustained turn performance. Optimizing sustained turn performance involves maximizing turn rate over time, and is energy neutral (meaning an aircraft generally maintains airspeed and altitude). Optimizing instantaneous turn performance, however, involves minimizing turn radius, and is energy depleting (losing airspeed and/or altitude). Differences in engine thrust capability, weight of the aircraft, and aerodynamic design factors all affect the ability of an aircraft to gain, maintain, or lose energy. Assuming equally skilled pilots, a more powerful engine or improved aerodynamic qualities equates to better performance: either a smaller turn circle, better turn rate, or better ability to regain lost kinetic or potential energy (airspeed or altitude).

But understanding basic fighter maneuvers (also affectionately known as "dogfighting") involves more than knowing airspeed, altitude,

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[206] Hammond, 59.

and turn performance. Fighter aircrews also must understand attack geometry and the air-to-air weapons employment zone (WEZ).

Since the first aerial battles of WWI, fighter pilots have sought to maneuver into a position of advantage. Theoretically, a position of advantage is anywhere a pilot can employ weapons, but the enemy cannot. Before the advent of air-to-air missiles, this equated to an area behind an adversary, and within the maximum effective range of an aircraft's guns. The size and relative position of any WEZ is dependent on several factors, including energy, range, aspect angle, angle off, and closure. Energy has been explained, and range is self-explanatory. Aspect angle is the position of an attacker measured in degrees off a defender's tail. Angle off (AO) is referenced from an offensive perspective, and is the position of a defender in degrees off an attacker's nose. Closure is discussed further below.

Describing an aerial dogfight to a non-flyer is difficult, and not simply because of the amount of information that must be processed and acted upon while immense gravitational forces are simultaneously trying to pull the blood away from a pilot's brain. Mostly, a BFM engagement is difficult to comprehend because of the speed with which it happens. When fighter pilots give a BFM briefing, they describe the events using a cues-actions-mechanics mantra – *if you see this cue, then take this action, and here's exactly how to manipulate the aircraft's controls to perform said action*. It generally takes between ten and eleven minutes for a highly proficient instructor to accurately brief a single BFM engagement, which, in execution, usually lasts less than a minute. When Boyd was an instructor at the Fighter Weapons School, for example, he earned the nickname “Forty-Second Boyd,” based on his ability to win any dogfight in less than forty seconds.[207]

For decades, fighter pilots have been taught that during a dogfight, three “Golden Rules of BFM” apply: lose sight, lose the fight; maneuver in relation to the enemy; trade energy versus nose position wisely. When considering how CC&D affects aggressive visual maneuvering, the first rule indicates that it is important to understand the relationship between analysis time (or, the time it takes to complete a full OODA Loop cycle) and the CC&D fidelity required to have a positive effect.

During WWII, one ground camouflage unit concluded that “the aim of…concealment wasn’t to hide a target perfectly, but simply to baffle and disorient an enemy flier for the few critical moments of his bombing run.”[208] This same idea can be applied to aircraft camouflage as it pertains to aerial combat. Because they are highly dynamic by nature, the WVR air encounters that occur over a matter of seconds require only simple methods of deception. In other words, a simple deception that provides even a momentary distraction may be enough to provide an advantage.[209]

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207 Coram, *Boyd: The Fighter Pilot Who Changed the Art of War*, 5.
208 Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 82.
209 Rothstein and Whaley, 46.

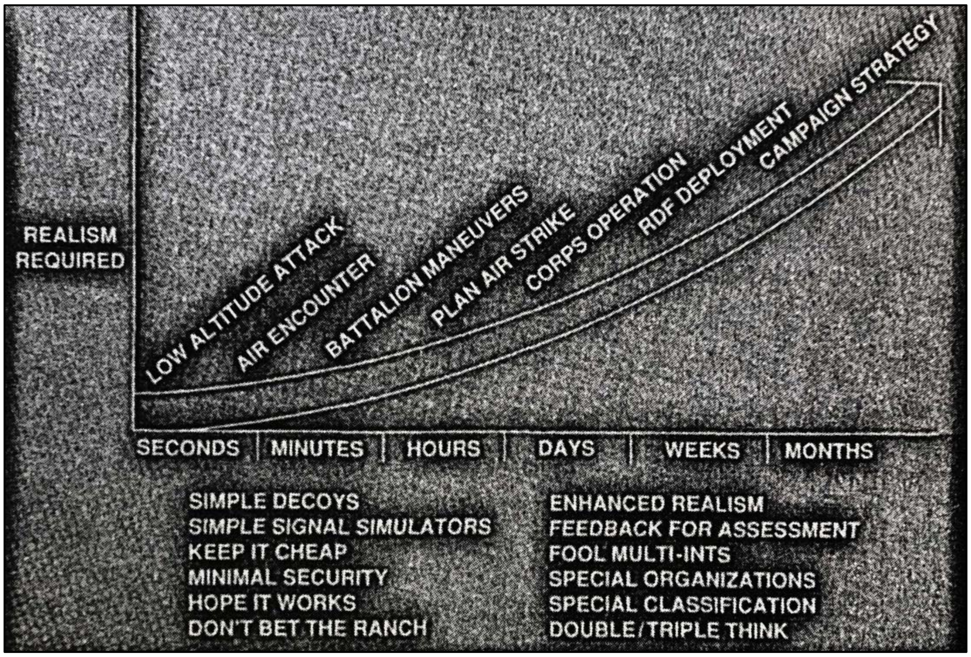

Figure 31: Analysis Time vs. Deception Fidelity Required
Source: Hy Rothstein and Barton Whaley, eds., The Art and Science of Military Deception (Boston: Artech House, 2013), 46.

When flying towards one another, the closing velocity (V_C) between two fighter aircraft typically approaches 1,000 knots (more than 1,150 mph). At 1,000 knots V_C, fighters close at approximately 1,690 feet per second. This means delaying an enemy's visual pickup (called "tally" in flying terms) by even 2-3 seconds can equate to 3,380 to 5,070 feet of closure, which is larger than the turn radius of most modern fighters. If a fighter can arrive at a merge (the point at which two opposing aircraft initially pass in a dogfight) unobserved, that fighter will have an offensive advantage in the ensuing dogfight. An aircraft that arrives at a merge with anything less than 180 degrees of Heading Crossing Angle (HCA) owns an advantage in the ensuing aerial engagement.

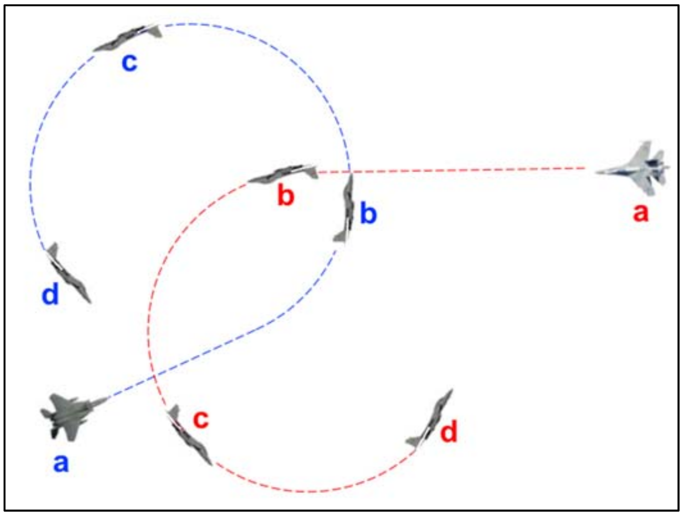

Figure 32: Diagram of Advantageous Merge Geometry
Source: Author's original work

Combining an understanding of BFM and Boyd's OODA Loop leads to several possible applications for WVR CC&D. Effective aerial CC&D can delay an enemy's initial tally, resulting in advantageous merge geometry. Once a visual engagement has begun, CC&D can further delay assessment of aspect angle, range, closure, and other WEZ recognition cues, slowing decision-making and forcing an enemy to execute a non-optimal game plan. Contributing factors to executing non-optimal game plans include momentarily losing sight, failing to recognize subtle energy or flight control cues, or bleeding energy unnecessarily, in violation of BFM's Golden Rules. Forcing an enemy into a non-optimal game plan may also result in a scenario where adversary WEZ recognition is so impaired that any fleeting WEZ opportunities that do exist are unrecognized.

In some cases, merely "disrupting the aircraft's configuration" may be enough to provide a momentary advantage.[210] If a paint scheme is misleading or distracting enough to limit an enemy's ability to determine

[210] Marrero-Camacho and McDermott, "(U) MASSTER Test Number FM 153: Camouflage Evaluation Report (Phase I)," 3–53.

an aircraft's configuration, this too can lead to sub-optimal BFM execution. Some aircraft have experimented with paint schemes (including several designed by Ferris) that artificially replicate canopies, tail shadows, armament stores, and other identifiable features on opposing sides of the jet.[211] Because each of these deceptions can lengthen the enemy's OODA Loop, potential advantages can be gained.

Figure 33: Deceptive vs. Normal Paint Schemes, F-16XL (underside)
Source: Adapted from Barry C. Wheeler, An Illustrated Guide to Aircraft Markings (New York, NY: Prentice Hall Press, 1986), 152.

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[211] Ferris, CAMOUFLAGED AIRCRAFT.

Chapter 3

From the Past, the Future

After examining the progression of aerial CC&D from WWI to modern day, as well as the implications of CC&D on WVR aerial maneuvering, an interesting question remains: What might the future of air warfare look like? While advancements in beyond-visual-range sensors and detection capabilities is not discussed in this text, history has shown that, given the time and technological know-how, as offensive capabilities improve, defensive capabilities also improve. If these offensive and defensive capabilities trend toward equilibrium, future conflict may well be informed by its WVR-rooted past. The reality of this cat and mouse game leads to several implications for today's USAF.

First, it is important that the US continue to recruit experts from non-defense-related industries when trying to solve modern military problems. The complexities and capabilities inherent in modern air warfare require the nation's brightest minds, and military members do not have a monopoly on developing innovative solutions to wicked problems. John Graham Kerr, known in Britain as the "father of the dazzle principle of ship camouflage," was one of England's leading scientists in 1914.[212] After the Great War began, Kerr, an expert in zoology and embryology, shared his expertise with British Admiralty after "studying the multihued, oddly patterned marine vertebrates on his laboratory shelves."[213] Dazzle-painting of Allied warships in WWI (and later WWII) was employed to "alter the apparent speed and direction of a vessel, and in that way confuse range officers aboard German

[212] Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 195.
[213] Reit, 195.

submarines."[214] This concept eventually extended to the air domain. Although US P-51 fighters that experimented with various dazzle-design paint schemes in WWII "were rarely used in combat,"[215] they represent a noteworthy collaboration between diverse communities of practice.

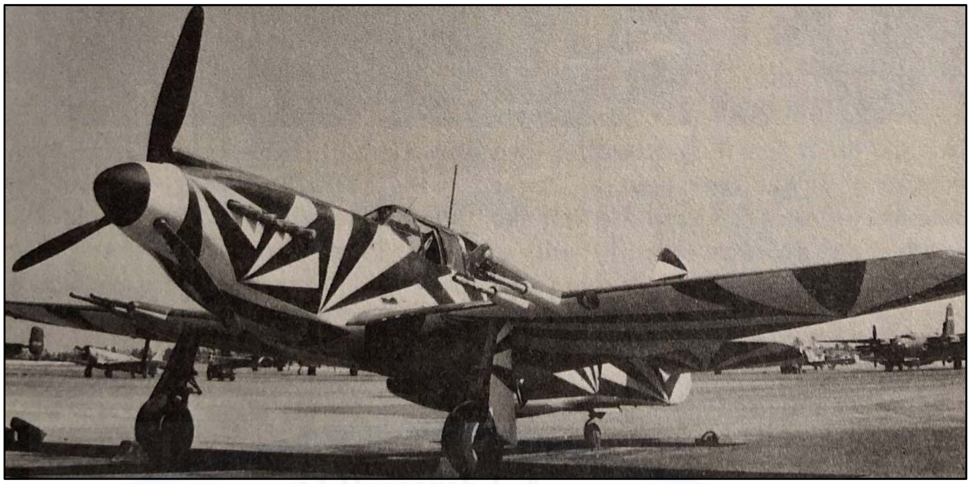

Figure 34: P-51 Dazzle-Design Experiment in WWII
Source: Seymour Reit, Masquerade: The Amazing Camouflage Deceptions of World War II (London: Hawthorn Books, Inc., 1979), inset picture #25.

While the effectiveness of the dazzle-type paint schemes tested in WWI and WWII was questionable, the intent to confuse an attacker is a valid air warfare concept that has critical implications for WVR aerial maneuvering. It is also interesting to consider that the checkered and dazzle paint schemes from WWI and WWII may have been the precursor of the computer-designed "digi-camo" patterns of the modern era. While not considered camouflage, per se, both are forms of concealment and deception that can be applied to the air domain. Vehicle manufacturers employ this black and white checkered design when testing the latest models in their lineup: concealing distinguishing features from prying eyes (or sensors) helps to protect company interests.

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[214] Reit, 65.
[215] Reit, inset picture #25.

Aerial dogfighting involves aggressive visual maneuvering. Although modern fighters are equipped with advanced sensors and highly automated display systems, oftentimes these close-range dogfights occur without the added benefit of any sensor-derived situational awareness or adversary information. This means that pilots are forced to visually assess range, aspect, and closure cues to determine whether a valid weapons employment zone exists, as well as subtle energy cues that help inform follow-on BFM options. BFM and OODA Loop applications are obvious: delaying an attacker's ability to correctly observe and orient ("maneuver in relation to the bandit") leads to delayed (missed WEZ opportunities) or incorrect (invalid weapons employment) WEZ assessments. The result is either a missed weapons employment opportunity or an invalid weapons employment attempt for the attacker, both of which benefit a friendly target.

The most important implication of the likely return to WVR combat is that the USAF must continue to invest in CC&D for the future of air warfare, focusing on both developing new capabilities and bolstering partnerships with industry and universities in new areas of research. This investment in CC&D should include research involving how future air assets might evade long-range detection from a variety of sensors, then transition from a beyond-visual-range environment to the WVR arena, arriving at a merge in a highly advantageous situation. Last year, USAF leaders allocated over $28 billion for research, development, test and evaluation (RDT&E) in the FY 2018 budget, and is currently allocating over $40 billion in FY 2019.[216] The USAF's FY 2019 Research and Development Budget request contains $6.949 million in "Tactical

[216] Office of the Under Secretary of Defense (Comptroller), "Department of Defense Budget Fiscal Year 2019: RDT&E PROGRAMS (R-1)," 2018.

Deception," but this involves the development of "non-kinetic airbase defense" capabilities, and is not related to deception in air warfare.[217] Part of investing in the future of aerial CC&D involves wanting to reduce the electromagnetic radiation signatures (along with the optical and IR signatures) of modern assets, sometimes termed "electromagnetic camouflage."[218] In the unclassified portions of the budget, it is unclear whether the USAF is investing in these types of capabilities. Given the secretive nature of modern CC&D techniques (and the obvious desire and need to protect advanced capabilities), most of the investment in this field would likely not be included in budget documents accessible to the public.

Examining how the USAF plans to allocate its RDT&E-apportioned funds towards CC&D capabilities can aid in understanding what the service views as priorities for future air warfare. According to official budget documents, the USAF is investing slightly more than $2 million into research and development of electro-optical, infrared, and radio frequency countermeasures for air assets in FY 2019.[219] It is also investing more than $5.7 million into the development of airborne electronic warfare capabilities.[220] More than $11 million is being invested in low-observable performance, and over $12.2 million is dedicated towards research, development, test and evaluation of thermal management materials.[221] An additional $8.1 million is allocated towards

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[217] Office of the Under Secretary of Defense (Comptroller); Department of Defense, "Fiscal Year (FY) 2020 Budget Estimates: Research, Development, Test & Evaluation, Air Force Vol-III Part 1," 2019, 767.
[218] Rothstein, Hy, and Barton Whaley, eds. *The Art and Science of Military Deception.* Boston: Artech House, 2013, 51.
[219] Department of Defense, "Fiscal Year (FY) 2020 Budget Estimates: Research, Development, Test & Evaluation, Air Force Vol-II," 2019, 533.
[220] Department of Defense, 596.
[221] Department of Defense, 246–47.

nanostructured and biological materials intended for aircraft structures, propulsion, and subsystems.[222]

While these RDT&E investments are allocated to areas important to modern aerial combat, perhaps the most promising area of the USAF's budget allocation involves the established partnerships with civilian academic institutions. Over $164 million is allocated towards "University Research Initiatives," and, while this total is spread across a wide spectrum of air-related research, several promising developments may directly impact the future of CC&D aerial capabilities.

Other Aerial Deception Methods

One enduring problem in the development of aerial CC&D is that no paint scheme or color pattern will camouflage an aircraft throughout all phases of flight because there are simply too many variables to contend with (illumination level, weather, altitude, and enemy sensor capability, to name a few). Post-WWI testing determined that, no matter the type of paint applied, "an aircraft always appears dark against the sky."[223] The invention and testing of Yehudi lights on sub-hunting maritime aircraft was one attempt at overcoming this phenomenon. Attempting to match the level of background ambient light to delay the visual acquisition of aircraft, F-4s conducting air-to-ground missions also experimented with the concept during Vietnam. While the concept was never fully proven effective, an interesting question remains: what if modern technology could revitalize this old idea? This might involve not just matching ambient light conditions, but matching the exact

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222 Department of Defense, "Fiscal Year (FY) 2020 Budget Estimates: Research, Development, Test & Evaluation, Air Force Vol-I," 2019, 27.
223 Hartcup, *Camouflage: A History of Concealment & Deception in War*, 14.

background to make portions of an aircraft virtually invisible to the naked eye or optical sensor. Modern scientists have experimented with several ways to achieve this phenomenon, one of which involves the idea of an "invisibility cloak."[224] In what once seemed only possible in science fiction, demonstrations of this technology involve a very simple concept that has roots in the natural world.[225] First, an object must be able to accurately "see" or sense its surroundings. Next, an object must be able to project that scene onto an opposing surface. Modern technology makes this simple for flat surfaces, but the capability is now being developed for curved or even flexible surfaces.[226]

Technological advancements like this are expanding the realm of what was previously thought possible in the field of CC&D. The latest 5th-Generation US fighter, the F-35 Lightning II, already employs this concept, but in reverse. Advanced sensors on the outside of the aircraft can stream real-time imagery to the pilot's Helmet Mounted Display system, allowing pilots to essentially "look through" the aircraft.[227] Future technological advancements, driven by dedicated investment in RDT&E, may someday allow this idea to translate into truly adaptive camouflage for aerial vehicles. Instead of a pilot being able to "see through" the aircraft skin, the aircraft could display the scene sensed on the other side. Alternatively, materials with high visual-reflectance, such as those with polished mirror-type finishes, could be used to reflect a scene back toward an aerial or ground observer. Some species of fish

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224 Newark, *Camouflage*, 162.
225 Hanlon et al., "Rapid Adaptive Camouflage in Cephalopods."
226 Newark, *Camouflage*, 162–63.
227 "The F-35 Helmet: Unprecedented Situational Awareness," Lockheed Martin F-35 Lightning II, 2019, https://www.f35.com/about/capabilities/helmet.

utilize this technique, using highly reflective scales to conceal themselves from predators.[228]

Another promising option in the realm of adaptive camouflage might be derived from the field of biology, particularly from the study of octopus, cuttlefish, and other cephalopods. These sea creatures can near-instantaneously adapt the color, texture, and shape of their bodies to blend into a variety of backgrounds.[229]

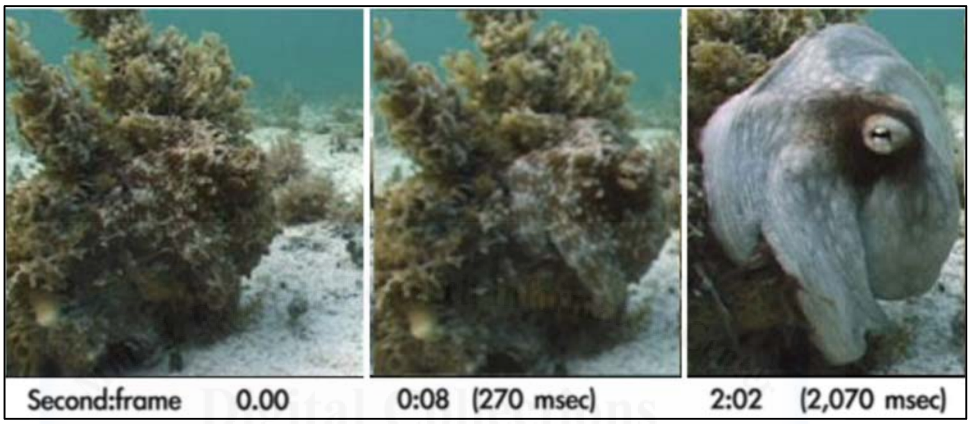

Figure 35: Rapid Adaptive Camouflage in Octopus
Source: Adapted from Roger T. Hanlon et al., "Rapid Adaptive Camouflage in Cephalopods," 2011, 146, https://www.researchgate.net/publication/283874370.

In one recent test, a multidisciplinary team comprised of American and Chinese experts, which were partially funded by research grants from the US Office of Naval Research and the Air Force Office of Scientific Research, created "adaptive optoelectronic camouflage sheets…capable of producing black-and-white patterns that spontaneously match those of the surroundings, without user input or external measurement."[230] In theory, as this technology matures, it may be possible for the individual

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[228] Newark, *Camouflage*, 12.
[229] Cunjiang Yu et al., "Adaptive Optoelectronic Camouflage Systems with Designs Inspired by Cephalopod Skins," *PNAS* 111, no. 36 (2014): 12998–3, www.pnas.org/cgi/doi/10.1073/pnas.1410494111.
[230] Yu et al. ONR Grant N00014-10-1-0989; AF OSR Grant FA9550-09-0346.

optoelectronic diodes to shrink in physical size while also expanding in capability, enabling reproduction of a more diverse range of colors.

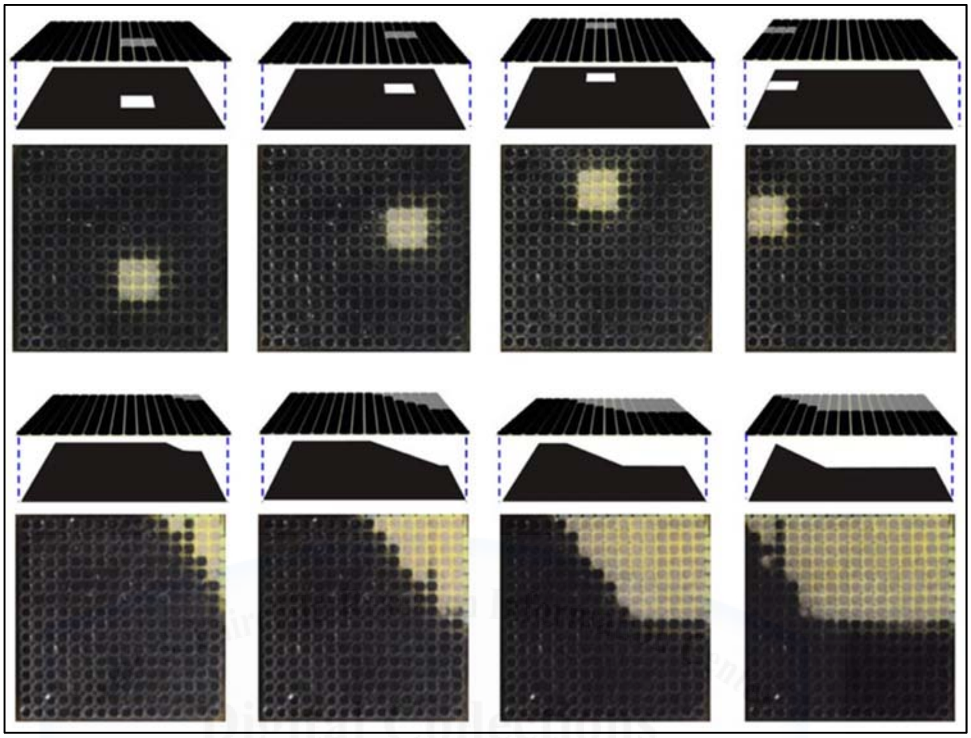

Figure 36: Adaptive Optoelectronic Sheets – Pattern Matching to Continuously Changing Background
Source: Cunjiang Yu et al., "Adaptive Optoelectronic Camouflage Systems with Designs Inspired by Cephalopod Skins," PNAS *111, no. 36 (2014): 12998–3, www.pnas.org/cgi/doi/10.1073/pnas.1410494111.*

In another experiment based on the adaptive camouflage concept, a joint Massachusetts Institute of Technology and Duke University team created synthetic polymers that, mimicking cephalopod skins, can change color and texture in response to controlled voltage. Experiments such as these offer potentially game-changing applications to the future of aerial CC&D, but will require continued research into the "intersectional fields of computational design, additive manufacturing, materials engineering, and synthetic biology."[231]

In a modern-day application of early German efforts to camouflage aircraft with various colors and patterns using printed fabrics, one US company has produced a "Flexible Multispectral 3D Combat Camouflage System" that enables users to take a picture of a local environment, then print that scene onto a special fabric-type material.[232] The fabric material is multispectral in nature, in that it provides both visual and IR protection. Eventually, it might also provide protection from enemy radar and other forms of electronic detection. This concept could benefit from continued development of 3D printing technologies, and may someday enable large assets to more easily blend into a local environment. Like the tension experienced in early aircraft camouflage between concealment and identification, the development of aircraft camouflage has also witnessed a constant tradeoff between CC&D for aircraft on the ground (when most vulnerable) and aircraft in the air (when looking to maximize mission effectiveness). Focused RDT&E and investment in this area could be a potential solution to this CC&D tradeoff dilemma, allowing air forces to optimize permanent camouflage for airborne mission effectiveness, while also protecting aircraft on the ground during temporarily dispersed combat operations.

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[231] "Design at the Intersection of Technology and Biology," Neri Oxman, TED Talks, https://www.youtube.com/watch?v=CVa_IZVzUoc, 29 October 2015.
[232] David Crane, "VATEC Concealment Solutions (VCS) Flexible Multispectral 3D Combat Camouflage System," Defense Review, 2015, http://www.defensereview.com/vatec-concealment-solutions-vcs-multispectral-3d-combat-camouflage-system-texturized-individual-and-vehicle-camouflage-by-polaris-solutions-israel-and-readyone-industries-conceals-your-visible-li/.

Conclusions

In the earliest forms of air warfare, most CC&D efforts focused on deceiving an enemy in the visual arena. As sensor and aircraft technology progressed, aerial CC&D efforts soon transitioned to the beyond-visual-range arena. Nearly every development of aerial combat capability has been driven by the need to counter an existing threat or maintain an advantage over current threat capabilities. Air forces throughout history directed immense effort towards implementing deception in air warfare. Wanting to evade visual detection, pilots employed visual camouflage techniques to either blend into the background or confuse an enemy observer. Capabilities were developed to allow aircraft to fly at night, where visual detection was greatly reduced. After radar was invented, special RAM coatings and specific aircraft shapes, electronic methods, and countermeasures were created to mask detection by radar and other types of sensors. An entire modern generation of low-observable aircraft employing a wide range of stealth technologies, including low RCS, RAM, and other materials was developed in response to advancing threat capabilities. To mask detection in the IR spectrum, new aircraft designs were invented to reflect or hide heat sources, and unique materials and systems were employed that dissipate heat quickly. Examining the historical progression of CC&D in air warfare, it is apparent that for every capability advantage gained, a counter capability has inevitably followed that neutralized or exceeded the original. To that end, modern CC&D techniques must build on the lessons of the past.

Despite amazing advancements in aircraft and long-range offensive weapons technologies, a corresponding progression of defensive capabilities (or restrictive air-to-air rules of engagement) present the very real possibility of aerial warfare returning to the WVR arena. When it does, high-tech USAF assets must be armed with every advantage, possibly including low-tech CC&D solutions based on historical means and methods. Modern 5th-Generation fighter aircraft such as the F-22 and F-35 currently possess the world's best stealth technologies and offensive air-to-air missiles, yet neither of these characteristics guarantee that WVR maneuvering will not be a part of future aerial engagements. The F-22, currently the USAF's premiere air-to-air fighter, holds an energy-maneuverability advantage over every other manned fighter in the world, but even this does not eliminate the need for continued investment in WVR deception methods. Adversary aircraft are currently being tested and developed that may soon challenge the F-22's aerial dominance, both in terms of denying BVR detection and WVR maneuverability. In large-scale exercises, 5th-Gen fighters such as the F-22 regularly find themselves at the merge with not just single, but multiple adversary aircraft, each equipped with all-aspect air-to-air missiles. In situations such as this, every advantage, including basic visual deception methods, must be utilized if the USAF hopes to realistically maintain WVR survivability.

Additionally, the emerging operating environment will likely be even more congested, both with physical assets (manned and unmanned aircraft) and assets utilizing the frequency range comprising the entire electromagnetic spectrum. Tests have proven that beyond-visual-range air-to-air missiles are far from perfect – each type, whether radar- or IR-guided, are susceptible to various forms of countermeasures. Combining this knowledge with a lesson from Vietnam, it is important that future USAF fighter aircraft possess some form of direct-fire weapon that is impervious to electronic or physical countermeasures. For the F-22, F-35, and every other modern USAF fighter, this currently exists in the form of an air-to-air 20mm, 25mm, or 30mm Gatling gun. Regardless of the type of platform the USAF chooses for its next-generation fighter, which is officially referred to as Penetrating Counterair, a direct-fire, kinetic kill capability should be combined with multiple forms of aerial CC&D to maximize lethality.[233]

What can the USAF learn from the developmental progression and employment methods of CC&D that will enable it to have a long-term advantage over its adversaries? First, it must accept that, although impossible to account for every weather condition or enemy sensor, every effort must be made to optimize friendly aerial CC&D for the intended operating environment. Prior to WWII, the Air Corps Tactical School (ACTS) understood that "the radius of action of Bombardment aviation is so great that even on a single mission, the nature of the terrain and weather conditions will change quite rapidly," and concluded that "every resort must be made to the use of that type of camouflage and coloring as will be the most effective over the greater part of the route."[234] In other words, camouflage must be optimized for the portion of the mission that is most important: typically the area of greatest threat or in the immediate area of the target. In regards to air warfare, ACTS also taught that "stress must be laid on deception rather than invisibility."[235] Until a generational leap in technology is realized, these observations by ACTS will hold true.

Second, given the amazing technological advancements discussed above, deception methods will benefit air warfare for the foreseeable future. Therefore, the USAF must adopt the mentality that Military Deception (MILDEC) is a required piece of its approach to war planning.

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[233] Enterprise Capability Collaboration Team, "Air Superiority 2030 Flight Plan," 2016, 7, https://www.af.mil/Portals/1/documents/airpower/Air Superiority 2030 Flight Plan.pdf.
[234] 1Lt George W. Hansen, "ANTIAIRCRAFT DEFENSE--PASSIVE MEASURES PART II" (Maxwell Field, Alabama, 1937), 18.
[235] Hansen, 18.

The relationship between MILDEC and operational planning is spelled out in Joint Publication 3-13.4, *Military Deception*. As staff manning shortfalls pervade across the Joint force, however, commanders must strive for a fully manned, equipped, and empowered MILDEC unit. The correlation of deception activities with successful military operations (across all forms of warfare) has been thoroughly addressed by Barton Whaley and other modern theorists.[236] Even the best operational plans are made more effective by including MILDEC activities throughout the planning process. Studies have shown that, even if detected, the mere presence of MILDEC activities help to extend an adversary's OODA Loop.[237]

Third, the USAF must not attempt to develop aerial CC&D capabilities on its own. History has shown that partnering with industry and recruiting experts from fields outside the military to advise and assist in CC&D development can yield innovative solutions to military problems. The immense benefit yielded from past civil-military partnerships has enabled the USAF to maintain an advantage in the air domain, and the potential advantage gained from possible future CC&D capabilities may allow the USAF to continue its dominance. Leveraging outside talent allows USAF leaders to build on lessons from the past, while exploring exciting new possibilities for future air warfare.

In demonstrations during WWII, camouflage experts allowed onlookers to "discover" several poorly-concealed snipers in a field. After the observers had "finally completed the hunt and congratulated themselves on their sharp vision," an additional seventy snipers emerged

[236] Barton Whaley, *Practise to Deceive* (Naval Institute Press, 2016).
[237] Rothstein, Hy, and Barton Whaley, eds. *The Art and Science of Military Deception.* Boston: Artech House, 2013.

from well-camouflaged locations, many of which were "literally within a few yards of the onlookers."[238] Similarly, large-scale USAF and Joint air exercises, such as the USAF Weapons School Integration phase, RED FLAG, and NORTHERN EDGE exercises, have proven that even the most high-tech 5th-Gen aircraft alone are not as effective as when integrated with lower-tech 4th-Gen assets. This proven concept involves "raising the noise threshold" to enable the enemy to see or perceive only that which you intend for them to; the aim is to deny, disrupt, or delay the ability of the enemy to perceive reality. This enables friendly forces to operate within the enemy's OODA Loop, gaining advantage with each decision-cycle.

Determining precise measures of effectiveness for aerial CC&D methods of the past is difficult, if not impossible to gauge objectively. Subjectively, however, the historical effort and investment witnessed in the development of CC&D by both military and civilian sectors alludes to both the importance and effectiveness of integrating CC&D into air warfare. Based on this author's operational experience, WVR deception methods such as camouflaged paint schemes, specialized aircraft shapes, and optimized visual signature management methods are effective in initially denying long-range tallies, and subsequently delaying WVR assessment of critical BFM-related visual cues. These effects typically translate into an offensive advantage for the aircraft employing CC&D methods, ultimately increasing survivability in WVR engagements.

Has the USAF approached the pinnacle of aerial deception? Based on the progression of means and methods employed in aircraft camouflage, history would suggest it has not. To best prepare for the air warfare of tomorrow, continued investment in CC&D is a must.

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[238] Reit, *Masquerade: The Amazing Camouflage Deceptions of World War II*, 86.

Additionally, the USAF should allocate the budget and manpower resources required to establish dedicated CC&D training and academics for its airmen.[239] Operational units should also emphasize deception methods in its daily training regimen, and include CC&D in every large force exercise. If the US hopes to maintain a continuing military advantage for the foreseeable future, it must learn from its past and make aerial CC&D an enduring priority.

[239] Rothstein and Whaley, *The Art and Science of Military Deception*, 53.

Appendix A

Organic Coverings: Modern USAF Aircraft Regulations

The process of applying various coatings to modern USAF aircraft has changed immensely since WWI. No longer can individual pilots, mechanics, or even units paint their aircraft in various shades of favorite colors. A variety of regulations govern modern USAF aircraft paint schemes and types of organic coverings. Notably, the term 'organic coating' "includes some heavy elastomeric materials which are not truly 'paints'."[240] MIL-STD-7179 covers the "general requirements for protective finishes and coatings on [US] aerospace weapon system structures and parts."[241] Today, "each MAJCOM prepares a supplement to Air Force Instruction 20-114 pertaining to painting and marking of aircraft."[242] Additionally, Technical Order (T.O.) 1-1-8 labels "HQ USAF/A4 responsible for coordinating AF painting and marking policy," and directs that each "System Program Director (SPD) [is] responsible for maintaining approved paint schemes."[243]

According to Air Force Materiel Command Instruction (AFMCI) 21-117 (dated 28 May 2014), modern paint schemes are applied in accordance with Technical Order (T.O.) 1-1-8 and the applicable aircraft T.O.[244] It goes on to state that a "4-6 year overcoat life expectancy" is

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240 "T.O. 1-1-8: APPLICATION AND REMOVAL OF ORGANIC COATINGS, AEROSPACE AND NON-AEROSPACE EQUIPMENT, Change 15," 2015, 1–1.
241 "T.O. 1-1-8: APPLICATION AND REMOVAL OF ORGANIC COATINGS, AEROSPACE AND NON-AEROSPACE EQUIPMENT, Change 15," 1–1.
242 "T.O. 1-1-8: APPLICATION AND REMOVAL OF ORGANIC COATINGS, AEROSPACE AND NON-AEROSPACE EQUIPMENT, Change 15," 8–1.
243 "T.O. 1-1-8: APPLICATION AND REMOVAL OF ORGANIC COATINGS, AEROSPACE AND NON-AEROSPACE EQUIPMENT, Change 15," 8–1.
244 AFMCI 21-117, "Corrosion Control and Prevention Program and Marking of Aerospace Equipment," 2014.

typical for most modern aircraft coverings.[245] AFMCI 21-117 also outlines the process for changing an approved paint scheme, dictating that "HQ AFMC/A4M is the point of contact for aircraft painting and markings."[246] AFMCI 21-117 also explains the special procedures required for "aircraft with low observable coatings, to include F-16 aircraft with Uniform Have Glass," which is an example of one type of covering that decreases the radar cross-section (RCS) of certain aircraft.[247]

245 AFMCI 21-117, 5.1.
246 AFMCI 21-117, 5.1.
247 AFMCI 21-117, 5.4.

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