# IFRI STUDIES

SECURITY STUDIES CENTER

FOCUS STRATÉGIQUE

No. 122

JANUARY 2025

# The Future of Air Superiority

## Command of the Air in High Intensity Warfare

Adrien GORREMANS
With the participation of Jean-Christophe NOËL

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ISBN: 979-10-373-1086-6



Cover: *Rafale* and *Mirage 2000* flying in formation

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**How to quote this publication:**

Adrien Gorremans with the participation of Jean-Christophe Noël, "The Future of Air Superiority: Command of the Air in High Intensity Warfare",
*Focus stratégique*, No. 122, Ifri, January 2025.

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# *Focus stratégique*

Resolving today's security problems requires an integrated approach. Analysis must be cross-cutting and consider the regional and global dimensions of problems, their technological and military aspects, as well as their media linkages and broader human consequences. It must also strive to understand the far-reaching and complex dynamics of military transformation, international terrorism and post-conflict stabilization. Through the "**Focus stratégique**" series, Ifri's Security Studies Center aims to do all this, offering new perspectives on the major international security issues in the world today.

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# Executive summary

Air superiority, understood as control of the air, is a cornerstone of the Western art of warfare. It is a decisive condition, albeit not sufficient by itself, to achieve military victory, as it enables the concentration of air power toward the achievement of wider strategic objectives and protects other components from unbearable attrition levels. It is best achieved through the offensive use of air power in a joint effort to neutralize the enemy's air power.

The recent developments of Russian and Chinese air power challenge the West's ability to acquire air superiority, particularly in the field of integrated air defense systems. The proliferation of ballistic and hypersonic technologies, drones, access to advanced electronic warfare technology, and the emerging exploitation of very high altitudes are potential game changers that might bypass or undermine the traditional Western paradigm of air dominance.

Radar stealth and the suppression of enemy air defenses (SEAD) are likely to remain the dominant factors of tactical superiority in air combat over the next decade. In addition, any force structure that will have switched from a platform-centric mindset to saturation and distribution strategies, while mastering a certain number of associated technologies, will gain a decisive edge in the battlespace.

The French air power is built around two main missions: nuclear deterrence and the air defense of mainland France. It is reaching the limits of its ability to weigh decisively within large coalitions fighting in high-intensity conflicts, due mostly to the absence of stealth platforms and SEAD capabilities, as well as to its undersized fleet of combat aircraft, lack of mission systems, and insufficient ammunition stockpiles.

This study lists several recommendations, broadly aiming at:

- maintaining the short- and medium-term relevance of the current fleet of combat aircraft by modernizing their mission systems and increasing weapons stockpiles;
- moving from a platform-centric approach to a network of distributed sensors and weapons working together to regain a form of mass;
- in the medium term, freeing fighter aviation from the Augustinian cost spiral, by ensuring the cost-effectiveness of its exquisite capabilities and employing them only where they are needed, while building a high-low mix of differentiated stand-in and standoff platforms.

# Résumé


La supériorité aérienne, concept clé dans l'art de la guerre occidental, définit le degré de maîtrise de l'air dans un conflit armé. Condition nécessaire mais non suffisante à la victoire militaire, elle permet de concentrer les efforts aériens au profit des autres objectifs stratégiques et de prémunir les autres armées d'une attrition insupportable. Elle s'obtient par un emploi offensif de la puissance aérienne dans un effort interarmées, afin de neutraliser la puissance aérienne adverse.

Les évolutions récentes de la menace aérienne russe et chinoise remettent en question la capacité occidentale à acquérir la supériorité aérienne, en particulier dans le domaine des défenses sol-air qui présentent un formidable défi aux forces aériennes européennes. La prolifération de technologies balistiques et hypersoniques, la dronisation, l'accès à des moyens avancés de guerre électronique et l'exploitation naissante de la très haute altitude constituent des ruptures capacitaires ayant le potentiel de contourner ou d'épuiser la domination aérienne occidentale.

Le combat aérien de la décennie à venir devrait rester dominé par la furtivité radar et l'impératif de neutralisation des défenses sol-air adverses (SEAD), mais verra aussi un avantage donné aux modèles de force qui auront basculé de la logique de plateformes vers une logique de saturation et de distribution tout en maîtrisant un certain nombre de technologies clés.

Le modèle de force français est construit autour de la dissuasion et de la défense aérienne du territoire métropolitain. Il atteint ses limites pour peser efficacement en coalition dans un conflit de haute intensité, en particulier en raison d'impasses sur la furtivité et la SEAD, et du volume insuffisants des flottes, des équipements de mission et des munitions.

Plusieurs recommandations sont formulées dans cette étude :

- maintenir la pertinence à court et moyen termes de la flotte actuelle d'avions de combat français en modernisant leurs équipements de mission et leur armement ;
- passer d'une logique de plateformes à une logique de capteurs et d'armement distribués travaillant collaborativement pour massifier l'engagement des forces aériennes ;
- à moyen terme, sortir l'aviation de chasse de la spirale augustinienne en ne payant le prix des capacités les plus haut de spectre que là où elles sont indispensables, et construire une force différenciée entre *stand-in* et *standoff*.

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# Introduction

On the night of January 16–17, 1991, the US-led coalition launched a major air campaign against Saddam Hussein's Iraq in preparation for the liberation of Kuwait, which Iraq had invaded six months earlier. At the time, Iraq possessed the sixth-largest air force in the world, battle-hardened by eight years of continuous war against Iran, equipped with modern Soviet and French combat aircraft, and supported by one of the densest ground-based air defense (GBAD) networks in the world. Yet, within a week, Iraq's airfields had been devastated by relentless waves of attacks from hundreds of combat aircraft that were protected from GBAD systems by standoff jammer aircraft and anti-radiation missiles. As a result, the Iraqi Air Force ceased to exist as an effective combat force, with most of its surviving aircraft fleeing to the safety of former enemy Iran.[1] The coalition air forces then enjoyed near-total freedom of maneuver over Iraq and Kuwait, which they exploited by pounding Saddam Hussein's divisions for over a month. When the ground invasion began, on February 24, 1991, the Iraqi Army rapidly collapsed and retreated in disarray.

To secure this decisive military victory, the coalition implemented a joint strategy largely inspired by American Colonel John A. Warden III.[2] The central tenet of this strategy, consistent with the Anglo-American tradition of twentieth-century strategic studies, was the attainment of air superiority, broadly defined as freedom of action in the air domain. During the initial phase of Operation Desert Storm, coalition forces committed nearly all available air strike assets that were deployed in the theater, but also their land- and sea-based firepower.

For the next three decades, Western armed forces[3] enjoyed the advantages of air supremacy in all their military operations, stemming from their overwhelming technological superiority, against adversaries that were either nonexistent or, at best, weak in the air domain. In Bosnia (1995), Kosovo (1999), Afghanistan (2001), Iraq (2003), Libya (2011), the Sahel (2013), and the Levant (2015), none of the entities confronted by NATO or Western coalitions posed a serious challenge in the air.

1. B. S. Lambeth, "The Winning of Air Supremacy in Operation Desert Storm", RAND, 1993, available at: www.rand.org.

2. J. A. Olsen, *John Warden and the Renaissance of American Air Power*, Washington, DC: Potomac Books, 2007.

3. In this text, the term "West" will refer to the geographical, political, and military group consisting of NATO and the European Union, as well as those Pacific military powers allied with the United States whose armed forces are shaped by the American model of air power, namely Japan, Australia, New Zealand, and South Korea.

Today, the 2020 Nagorno-Karabakh war and the Russian invasion of Ukraine, unfolding in a geopolitical climate marked by the uninhibited use of force and great power competition, have reignited concerns about a return to air combat for NATO forces. In three years of war, both Russian and Ukrainian air forces have been effectively neutralized by the density and effectiveness of integrated air defense systems (IADS).[4] At the same time, evolving conflict dynamics and technological advances are shifting toward anti-access/area denial (A2/AD) strategies and countermeasures, prompting a reassessment of the Anglo-American doctrinal approach to air power, built on the lessons of the Second World War, the Korean War, and the Vietnam War, and validated by the 1991 victory in Iraq.

The question of NATO's ability to counter A2/AD has been under discussion since Russia's re-emergence as a major geopolitical actor in Europe.[5] In light of the evolving strategic landscape, this question deserves to be re-examined. Given recent technological advancements and the dissemination and proliferation of capabilities and doctrines for bypassing traditional air power, does the pursuit of air superiority by Western, and in particular French, force structures remain a viable objective? Is it still achievable, and, if so, under what conditions and constraints?

The structure of this study follows the framework used in NATO tactical air mission planning. Its core tenet is that regardless of the cost of attaining and maintaining control of the air, that cost will always be lower than the cost to the belligerent of losing the air battle. As a nod to the author's operational background, this study is structured into five phases: task, target, threat, tactics, and timeline. These represent the intellectual process that Western fighter crews follow in both tactical training and actual combat missions.

The first section (task and target) analyzes the concept of air superiority, or, to use Giulio Douhet's term, "command of the air".[6] After proposing a formal definition, it traces the historical evolution of the concept and examines the effect of air superiority on operations in other domains. The section concludes by outlining the doctrinal approach to air superiority as traditionally understood in the West, an approach validated by the 1991 Gulf War experience.

The second section (threat) assesses the West's potential adversaries, beginning with the evolution of Russian and Chinese air and GBAD threats, with a particular focus on long-range systems. It then examines the proliferation of capabilities designed to undermine and bypass traditional air power, notably deep-strike and drone warfare capabilities. These

4. J. Bronk, "How Ground-based Air Defences Have Shaped the Air War over Ukraine", in D. Henriksen and J. Bronk (eds.), *The Air War in Ukraine: The First Year of Conflict*, New York: Routledge, 2024, pp. 137–167.

5. C. Brustlein, É. Tenenbaum, and É. de Durand, *La Suprématie aérienne en péril: Menaces et contre-stratégies à l'horizon 2030*, Paris: La Documentation française, 2014, available at: www.ifri.org.

6. G. Douhet, *Il dominio dell'aria*, English translation by D. Ferrari: *Command of the Air*, Montgomery: Air University Press, 2019.

developments threaten Western air superiority by partially neutralizing its offensive paradigm, forcing investment in defensive capabilities that NATO has largely neglected since the end of the Cold War. The section concludes with an analysis of the state of mutual air denial that has characterized the war in Ukraine since early March 2022.

The third section (tactics) discusses the nature of modern air combat in the context of these threats, particularly in the realms of air-to-air combat and the suppression of enemy air defenses (SEAD), the two pillars of modern air superiority. It examines potential capability, tactical, and technological solutions to the challenges posed by technical advancements and counter-strategies described in the previous section.

Finally, the fourth section (timeline) examines the capabilities within the French force structure that contribute to air superiority, in the specific framework of France's defense strategy. It identifies several material and doctrinal vulnerabilities. The most critical of these hinges on capabilities and involves stagnation in key technological sectors and a lack of overall organic depth. The section concludes with recommendations—for both the immediate future and over the course of the next decade—to strengthen the French model and maximize its chances of prevailing in a major air confrontation.

# Task – Control of the air

Defining air superiority requires both an understanding of the unique characteristics of the air domain and a historical approach to air strategy. This definition is based on two fundamental concepts: first, its dual nature as an offensive and defensive notion; second, its temporal and spatial dynamics. Since the end of the Second World War, control of the air has become an operational imperative, a necessary but not sufficient condition for military success that facilitates operations across all domains and environments. Western doctrine, shaped by a century of air warfare and validated in 1991 in Iraq, places particular emphasis on achieving air superiority, which requires concentrating joint offensive efforts at the outset of a campaign while maintaining the minimum sufficient defensive force to secure the rear area.

## Defining air superiority

Defining air superiority requires a threefold conceptual approach. First, as with any form of domain superiority, it is essential to understand the physical characteristics of airspace and their practical implications for the nature of combat and the systems that operate in it. Second, the history of air power theories offers insight into the intellectual foundations of air superiority. We can build on these two conceptual pillars to propose a doctrinal definition applicable to all air operations regardless of their historical context.

### *Unique characteristics of the air domain*

The air domain has only recently been scientifically explored and exploited by humans. Its physical characteristics distinguish it fundamentally from the other two historical domains of conflict: land and sea. These unique attributes mean that “air power offers the advantage of finding, fixing and engaging adversary surface forces across the full depth of the battlespace, without many of the physical, spatial, and environmental limitations imposed on surface forces”.[7]

First, the air domain is three-dimensional and provides a highly permissive operational environment, with no physical constraints on border crossings and no natural obstacles to movement. Aircraft have the potential to access any point on the globe.[8]

7. Allied Joint Publication 3.3, Edition B, Version 1, “Allied Joint Doctrine for Air and Space Operations”, *NSO*, April 2016, pp. 1–3, available at: https://assets.publishing.service.gov.uk.
8. Ibid., pp. 1–2.

In the context of the contest for control of the air, airspace can be categorized into several altitude bands:

- Low altitude (below 5,000 feet): the domain of rapid-fire anti-aircraft artillery (AAA), helicopters, light drones, cruise missiles, and fighter aircraft attempting to fly below the detection envelope of enemy radars, using terrain for masking.
- Medium altitude (5,000 to ~25,000 feet): characterized by the presence of short-range surface-to-air missiles (SAMs), medium-altitude long-endurance (MALE) drones, fighter aircraft, light surveillance aircraft, and tactical transport aircraft.
- High altitude (25,000 to 66,000[9] feet): the operational space for fighter aircraft, tactical support and intelligence aircraft (air-to-air refueling tankers, airborne early warning [AEW] aircraft,[10] electronic warfare aircraft, high-altitude long-endurance [HALE] drones, etc.), and long-range transport aircraft. Only medium- and long-range SAMs are capable of engaging targets at these altitudes.
- Very high altitude (66,000 feet to the Kármán line):[11] An emerging conflict zone involving certain reconnaissance aircraft, ballistic and hypersonic weapons, reconnaissance balloons, and certain long-range SAMs.

The atmosphere is transparent to electromagnetic waves in the radio and radar frequency bands. In the ultraviolet, visible, and infrared spectra, it is partially transparent because the microdroplets and microcrystals that make up clouds are opaque to these wavelengths. As a result, the atmosphere is a highly sensitive domain for electromagnetic spectrum superiority, particularly in radar detection, radio communications, electronic warfare, and, weather permitting, electro-optical systems. As stealth technology will be extensively discussed later, it is important to note that reducing an aircraft's radar cross-section (RCS) by one order of magnitude results in approximately a 50% reduction in radar detection range.[12] For the sake of simplicity and confidentiality, we shall categorize objects into three classifications in terms of stealth:

- non-stealth objects, with an RCS of approximately 1 $m^2$;
- low observable (LO) objects, with an RCS of approximately 0.1 $m^2$;

9. The 66,000-foot limit is used here because it corresponds to the vertical boundary of controlled airspace. Above this altitude, airspace remains under national sovereignty but is no longer managed by civil aviation authorities. This threshold is slightly higher than the maximum flight altitude of most combat aircraft, which is approximately 50,000 feet.

10. Radar aircraft (E-3 AWACS, E-2 Hawkeye, A-50 Mainstay, etc.).

11. The Kármán line is the internationally recognized boundary between the Earth's atmosphere and outer space. It is officially defined by the World Air Sports Federation (FAI) at 100 kilometers above sea level.

12. K. Zikidis, A. Skondras, and C. Tokas, "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies", *Journal of Computations & Modelling*, Vol. 4, No. 1, 2014, pp. 129–165, available at: www.researchgate.net.

- very low observable (VLO) objects, with an RCS below 0.01 m².

For a given altitude and aspect angle, if a non-stealth object is theoretically detectable by radar at a distance of 200 nautical miles (NM), an LO object would be detected at approximately 112 NM, while a VLO object would be detected only at around 36 NM.[13]

## *The concept of control of the air*

The strategic importance of control of the air became evident as early as the First World War. The emergence of fighter aviation, a specialized branch dedicated to achieving air superiority, is clear evidence of this. From a theoretical standpoint, many military thinkers explored the subject, but it was Giulio Douhet who left the most lasting impact with his work *Il dominio dell'aria*, first published in 1921 and revised in 1926.[14]

The English title, *Command of the Air*, is an obvious reference to Alfred Thayer Mahan, the author of *The Influence of Sea Power upon History, 1660–1783*.[15] Indeed, maritime strategists were the first to introduce the notion of domain superiority into the military lexicon. Mahan's contributions to maritime strategy were further refined in the early twentieth century by Julian Corbett, who introduced the concept of sea control. Corbett argued that control of an operational domain is not necessarily an absolute, permanent, or total state of superiority, but rather a situational advantage that can vary depending on strategic objectives and the resources available.

In the 1920s, Douhet's theories oscillated between two key priorities: "destroy[ing] the enemy air force at its bases" (i.e., the enemy's aeronautical industry), and developing a "battleplane"—an aircraft designed to both engage enemy air forces in combat and conduct strikes against surface targets.[16] However, Douhet's primary interest lay in the potential applications of such an air superiority. Achieving control of the air makes it possible to monopolize the third dimension of warfare and deny it to the enemy. Under such conditions, an adversary, faced with the prospect of sustained strategic bombardment, would have no rational alternative but to capitulate.

Among the air power strategists who further developed Douhetian air power theory, the most influential was John A. Warden III. In the 1980s, Warden redefined what it means to "be superior in the air", stating that: "to have air superiority, means having sufficient control of the air to make air attacks on the enemy without serious opposition and, on the other hand, to

13. *Ibid*, p. 137.
14. Douhet, *Il dominio dell'aria*, op. cit.
15. A. T. Mahan, *The Influence of Sea Power upon History, 1660-1783*, Boston: Little, Brown and Co, 1890.
16. T. Hippler, "L'évolution de la pensée politique et stratégique de Douhet", *Nacelles*, No. 9, 2020, available at: https://interfas.univ-tlse2.fr.

be free from the danger of serious enemy air incursions”.[17] Warden argues that air superiority is “crucial” to the success of military operations and that an air campaign will fail if the enemy gains control of the air, leading to catastrophic consequences for all components of the armed forces. To prevent such a strategic failure, these components must work together to acquire air superiority.

These strategists show that there are two sides to air control: the offensive aspect, which establishes the necessary conditions for friendly air power to operate effectively, and the defensive aspect, which denies the adversary the ability to exploit the air domain against friendly forces.

## *Defining the term*

Based on a century of air warfare, we can refine the theories of early air power strategists. For example, the state of air supremacy, as envisioned by Giulio Douhet, is rarely achieved in air warfare. In particular, three factors play a role in determining the degree of control of the air: duration, geographical and altitudinal extent, and the level of enemy contestation.

The duration of required air control can vary. It may be needed for only a few minutes when the objective is to strike a specific target, as in Operation Hamilton.[18] Conversely, it may extend throughout all phases of an air campaign, as in Operation Desert Storm.[19]

From a geographical perspective, control of the air can be limited to the defense of a vital point of interest, such as critical infrastructure, a command and control (C2) center, or a gathering of heads of state. In such cases, control of the air extends over a radius of less than ten kilometers, though it must account for the speed of incoming aircraft and effectively cover a significantly larger operational area. Control of the air is considered localized when its objective is to protect a specific operation or area, which may span thousands of square kilometers. At the highest level, it can encompass an entire theater of operations, country, or world region, potentially including lines of communication between the theater and allied nations. In this case, the area requiring coverage may reach hundreds of thousands of square kilometers.

In addition to horizontal coverage, altitude must also be taken into account. For both operational and technical reasons, control of the air may apply to a specific range of altitudes, allowing friendly aircraft to maneuver freely in certain layers, while other layers will be more hazardous (such as SAM systems’ envelopes) or physically inaccessible because of aircraft limits (such as engine operating restrictions).

17. J. A. Warden, *The Air Campaign*, Lincoln: iUniverse, 2000, p. 10.
18. E. Moyal, “Operation Hamilton… démonstration stratégique et puissance aérienne”, *Revue de la défense nationale*, June 2019, available at: www.defnat.com.
19. T. A. Keaney and E. A. Cohen, *Gulf War Air Power Survey, Summary Report*, Washington, DC: Library of Congress, 1993, available at: https://media.defense.gov.

Based on these considerations, a definition of modern air superiority could be: "Control of the air defines the freedom of action for friendly forces operating within the air domain, while imposing restrictions on adversary forces attempting to use the air domain against friendly forces. It is characterized by its duration, geographical scope, and altitude range".

Air superiority therefore represents an operational state that can fluctuate throughout an air campaign, depending on the level of engagement by both belligerents. It can be established over distinct areas of operations, at varying altitudes, and for a specific duration.

### Table 1: Variations in degree and intensity of control of the air (and practical examples)

| | Characteristic value | Application example |
|---|---|---|
| Duration | Minutes to tens of minutes | Protection of a target area during an offensive raid |
| | Hours to days | Protection for a specific event or operation |
| | Permanent | Sovereignty, long-term protection of an operation or strategic asset |
| Geographical scope | Tens of kilometers | Protection of a friendly center of gravity or a target area during an offensive raid |
| | Hundreds of kilometers | Protection of an area of operations or a front line |
| | Thousands of kilometers | Domain superiority over a theater of operations |
| Altitude | Low altitude (Ground – 15,000 ft) | Fighter aircraft<br>Tactical transport aircraft<br>Helicopters<br>Tactical drones<br>Cruise missiles<br>Anti-aircraft artillery<br>SAMs, including MANPADS<br>Anti-aircraft drones |
| | Medium and high altitudes (15,000 ft – 66,000 ft) | Fighter aircraft<br>Air-to-air refueling<br>Electronic warfare<br>Reconnaissance<br>Transport aircraft<br>MALE and HALE drones<br>SAMs |
| | Very high altitudes (66,000 ft – Kármán line) | Reconnaissance<br>Electronic warfare<br>Ballistic and hypersonic missiles |
| Intensity | Defensive parity | Both adversaries lack sufficient air power to exert significant air influence |
| | Offensive parity | Both adversaries possess air capabilities that can influence each other's military forces |
| | Air superiority | One side maintains operational initiative for air operations while being subject to non-prohibitive adversary air influence |

| | | |
|---|---|---|
| | Air supremacy | One side has near-total freedom of action in the air, while the adversary's air influence is minimal |
| | Air dominance | One side has absolute freedom of action in the air, and the adversary is unable to exert any influence in the air domain |

# The rationale for seeking air superiority

Air superiority allows air power to be employed without restriction across the full spectrum of joint tactical, operative, and strategic objectives.[20] It generates decisive effects across all domains and operational environments, but it is particularly effective in the kinetic domain, where the reach and speed of air operations surpass those of other military components.

## *A means to an end*

While theorists such as Douhet, Ritter,[21] and Warden have emphasized the necessity of achieving air superiority, what seems self-evident to aviators is not always universally accepted. Skepticism arises from the lack of a direct causal link between achieving military dominance in the air domain and securing victory in war. A conflict may still be lost in another operational environment, leading to more severe consequences, or on the political front, as seen in Vietnam, Afghanistan, or the Sahel. Even if enemy aircraft are systematically neutralized, such success does not necessarily prevent strategic defeat in the informational domain.

Over a century ago, the French high command was already wary of aviators' insistence on defeating German aces in aerial combat. They struggled to see the strategic value of clearing the skies if the enemy ground forces were able to take Paris.[22] However, between March and July 1918, Entente aircraft played a critical role on the battlefield, helping to halt the German offensives. Air assaults by Breguet 14 bombers had undeniable battlefield effects on June 11, 1918, during the Battle of the Matz,[23] where they disrupted enemy troop movements ahead of Mangin's counteroffensive. Likewise, on July 15, 1918, during the German crossing of the Marne, air strikes inflicted significant damage on enemy landing craft and demoralized troops attempting to cross the river.[24] These operations were only possible because German fighters did not prevent them.

The current rationale for seeking air superiority remains the same. Driving enemy aircraft from the skies does not directly guarantee victory, though in some cases, such as the Battle of Britain, it can lead the adversary

20. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–10.
21. H. Ritter, *La Guerre aérienne*, CESA, La Documentation française, 2013, p. 211.
22. General Voisin, *La Doctrine de l'aviation française de combat*, Paris: Lavauzelle, 1932, p. 39.
23. Ibid., pp. 135–138.
24. Ibid., pp. 139–143.

to abandon its offensive intentions. What air superiority does do is enable essential, even decisive, operative-level effects by granting friendly forces the freedom of action necessary for joint operations. This aligns with Foch's strategic principles: military actions are far more effective when they are not constrained by enemy air power. This is the defensive dimension of air superiority. With fewer resources diverted to defending against enemy air attacks, commanders gain operational flexibility and can allocate forces more effectively. Additionally, air superiority drastically reduces, or even eliminates, casualties from enemy air strikes. The United States Air Force (USAF) frequently underscores this point: since the Korean War, no American soldier has been killed by an enemy aircraft,[25] a testament to the resources invested in air superiority capabilities. Air superiority therefore is a critical support to joint maneuver warfare.

### *Effects of air superiority on other domains*

Field Marshal Bernard Montgomery summed up his understanding of air power at the end of the Second World War: "If we lose the war in the air we lose the war and we lose it quickly".[26] Air superiority enables air power to be applied without limit to the full range of joint tactical, operative, and strategic objectives,[27] at reduced human and material cost, leaving post-war Winston Churchill with the impression that "for good or for ill, air mastery is today the supreme expression of military power".[28]

When supporting land forces, air power delivers an unmatched concentration of firepower across all engagement ranges, from close air support (CAS) to air interdiction (AI), well beyond the reach of modern artillery and with a fire density far exceeding those achievable with the limited number of very long-range surface-to-surface weapons projected for the coming decade.[29]

CAS can reverse critical tactical situations, as demonstrated in the 2009 Battle of Kamdesh in Afghanistan.[30] A massive air strike can also create decisive breaches in enemy lines, as seen during Operation Cobra in the Normandy bocage in 1944.[31] More recently, the Russian military has been leveraging this tactical advantage with the large-scale introduction of the UMPK glide bomb guidance kit[32] in early 2024. Deployed from high altitude over controlled territory, these weapons have remained largely unchallenged

25. P. Grier, "April 15, 1953", *Air Force Magazine*, June 2011, available at: www.airandspaceforces.com.
26. Quoted in P. S. Meilinger, *Ten Propositions Regarding Airpower*, USAF School of Advanced Airpower Studies, Maxwell AFB, 1995.
27. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–10.
28. Speech by W. Churchill, MIT Mid-Century Convocation, Boston, March 31, 1949.
29. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–11.
30. J. Tapper, *The Outpost: An Untold Story of American Valor*, New York: Back Bay Books, 2013.
31. M. Hastings, *Overlord: D-Day and the Battle for Normandy 1944*, New York: Vintage Books, 2006.
32. "Russia Develops Guidance Modules for Air-dropped Munitions", *Ukraine Field Dispatch*, Conflict Armament Research, December 2023, available at: https://storymaps.arcgis.com.

because of the lack of Ukrainian fighter presence or adequate long-range SAM batteries, which instead cover Kyiv.[33] As one Ukrainian combatant, forced to withdraw from Avdiivka in April 2024, described it: "These bombs completely destroy any position. All buildings and structures are pulverized after the impact of just one, and they drop sixty to eighty on us in a single day".[34]

At the operative level, air interdiction slows or halts enemy forces from reaching the front line,[35] as seen in June 1944, when it took the 2nd SS Panzer Division *Das Reich* three weeks to reach Normandy amid aerial disruption.[36] It also restricts lateral movements behind enemy lines, facilitating exploitation of breakthroughs, such as the Allied advance in Italy in 1943.[37] Furthermore, interdiction can turn an orderly withdrawal into a rout, as demonstrated on the "Highway of Death" in Iraq in 1991.[38] Conversely, it can also preserve a retreating force from annihilation, as in the case of the US 8th Army's withdrawal during the Korean War in the fall of 1950.[39]

At the strategic level, air operations in support of ground forces can offset numerical inferiority on the battlefield and inflict unsustainable attrition on the adversary. This was exemplified during Operation Desert Storm, where coalition air forces systematically degraded the combat effectiveness and morale of the world's fourth-largest land army within 41 days.[40]

Beyond its overwhelming firepower, air power generates unique effects across all key aspects of deep land operations, particularly in reconnaissance, logistics, special operations, and medical evacuation. It provides unmatched flexibility, rapid response, and concentrated firepower.[41]

In the naval domain, the ability to concentrate firepower is especially critical because of the limited number of targets and their small surface footprint. Air superiority, however fleeting, is a key to achieving victory in naval combat.[42]

The transition from the battleship era to the aircraft carrier era during the Second World War highlights the decisive role of air power in naval combat. For example, during the Battle of Midway (June 3, 1942), 47 light

33. P. Butowski, "The Truth About Russia's Mysterious Winged Glide Bombs", *The War Zone*, July 19, 2023, available at: www.twz.com.
34. J.-P. Lefief, "Les bombes planantes, 'arme absolue' des forces russes, ou révélateur du sous-équipement des Ukrainiens?", *Le Monde*, April 23, 2024, available at: www.lemonde.fr. **Translator's note**: Our translation. Unless otherwise stated, all translations of cited foreign-language material in this article are our own.
35. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–10.
36. J. A. Warden, *The Air Campaign*, op. cit., pp. 76–77.
37. Ibid., pp. 78–79.
38. T. A. Keaney and E. A. Cohen, *Gulf War Air Power Survey, Summary Report*, op. cit., pp. 112–117.
39. J. A. Warden, *The Air Campaign*, op. cit., pp. 72–73.
40. T. A. Keaney and E. A. Cohen, *Gulf War Air Power Survey, Summary Report*, op. cit., pp. 102–117.
41. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–14.
42. Ibid., pp. 1–11.

bombers disabled three aircraft carriers in just five minutes.[43] By contrast, at the Battle of Surigao Strait (October 25, 1944), an overwhelming surface fleet required two hours to sink two obsolete battleships, a cruiser, and three destroyers.[44]

Since 1943 and the Battle of the Atlantic, air power has also proven to be a force multiplier in anti-submarine warfare, with its unique ability to cover vast oceanic areas and to detect, track, and neutralize submarines at range before they can engage friendly vessels.[45]

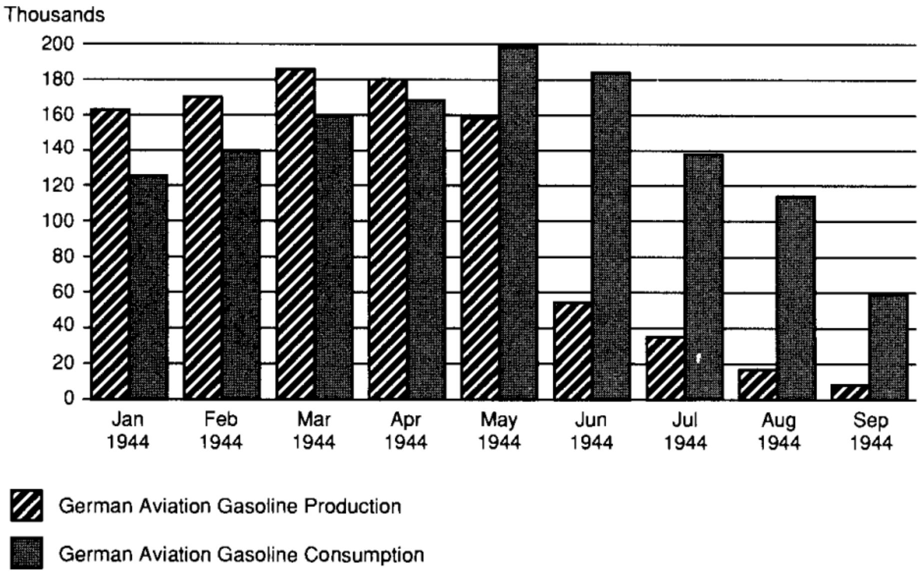
Finally, air power can deny access to naval bases and surprise enemy fleets at anchor, as at Pearl Harbor and Taranto.[46] It can also cripple the logistics essential for maritime operations and interdict strategic chokepoints.

In strategic terms, throughout the twentieth century, air power has demonstrated a unique ability to strike directly at adversary centers of gravity, overcoming geographical and military constraints. The effectiveness of these strategic strikes depends on the identification and systemic analysis of these centers of gravity, and therefore on the quality of targeting. Three historical examples stand out particularly:

- The destruction of enemy industrial production centers by the Allied Combined Bomber Offensive against Nazi Germany, initiated at the Casablanca Conference in January 1943, which yielded mixed results.[47]
- The disruption of transportation networks and resources essential to sustaining combat operations, exemplified by the near-total destruction of the Nazi oil industry by American air power in the latter half of 1944, which paralyzed the German military and part of its industrial base.[48]

43. W. J. Koenig, *Epic Sea Battles*, London: Peerage Books, 1975, pp. 212–232.
44. D. A. Johnson, "How the Battle of Surigao Strait Brought Revenge for Pearl Harbor", *Warfare History Network*, December 2008, available at: https://warfarehistorynetwork.com.
45. P. Facon, *La Guerre aérienne (1933-1945)*, Docavia, Éditions Larivière, 2003, pp. 114–121.
46. D. Harding, *Operation Judgment*, London: Magna Large Print Books, 2008.
47. *The United States Strategic Bombing Surveys (European War) (Pacific War)*, Maxwell Air Force Base, Air University Press, 2001, available at: www.airuniversity.af.edu; W. A. Jacobs, "Operation OVERLORD", *Case Studies in the Achievement of Air Superiority*, Air Force History and Museums Program, 1994, pp. 292–293; P. Facon, *La Guerre aérienne (1933-1945)*, pp. 135–146.
48. C. Gray, *Air Power for Strategic Effect*, Maxwell (Alabama): Air University Press, 2012, p. 143, available at: www.airuniversity.af.edu.

**Figure 1: German aviation gasoline production and consumption**




*Source: W A. Jacobs, "Operation OVERLORD", p. 297.*

- Finally, strategic paralysis through attacks on adversary centers of power, decision-making, and communication—an approach particularly emphasized by Warden.[49] While the sometimes extreme interpretations of this strategy may have undermined its credibility, it nevertheless proved remarkably successful in Iraq in 1991 and 2003 and in Serbia in 1999, and it remains central to modern Western air power doctrine.[50]

Air superiority is therefore rarely an end in itself, but rather a decisive condition that enables air power to act as a force multiplier alongside the other components, achieving decisive and rapid strategic effects and radically reducing the losses of all other components.

## *Air superiority and military victory*

This approach is supported by the findings of a recent academic study conducted by Richard Saunders and Mark Souva of Florida State University, which quantitatively analyzes the relationship between air superiority and battlefield victory.[51] As the authors show, air superiority enhances the maneuverability of friendly ground forces, allowing them to advance rapidly

49. D. S. Fadok, *La Paralysie stratégique par la puissance aérienne - John Boyd et John Warden*, Paris: Economica, 1999; E. Luttwak, *La Renaissance de la puissance aérienne stratégique*, Paris: Economica, 1998; J. A. Warden III, "The Enemy as a System", *Airpower Journal*, Vol. IX, No. 1, Spring 1995, available at: www.airuniversity.af.edu.

50. R. A. Pape, *Bombing to Win: Air Power and Coercion in War*, Ithaca: Cornell University Press, 1996; C. Gray, *Air Power for Strategic Effect*, op. cit., p. 52.

51. R. Saunders and M. Souva, "Air Superiority and Battlefield Victory", *Research & Politics*, Vol. 7, No. 4, October 2020, available at: www.researchgate.net.

and with minimal resistance toward weak points in the enemy battle line. Simultaneously, it creates the conditions necessary to more effectively halt an enemy offensive by providing additional firepower from the air. More broadly, air superiority facilitates integrated air-land operations.

The researchers examined 45 conflicts that occurred between 1932 and 2003, involving 99 participants. Their study yielded two primary conclusions. First, at the tactical level, in four out of five cases the victors of decisive battles had air superiority. In only two instances did a force with air superiority lose a decisive battle. However, these results require some qualification. The first exception was Italy's defeat by Greece in 1940, where British air support for Greek forces was not accounted for. The second was Cambodia's defeat by Vietnam. While Cambodia benefited from US bombing operations against the Viet Cong, there was no coordination between Cambodian forces and US air assets. According to the authors, air superiority is the most significant variable influencing the outcome of a battle. They even argue that it has a greater impact on the final outcome than adopting the modern ground forces system developed by Stephen Biddle.[52]

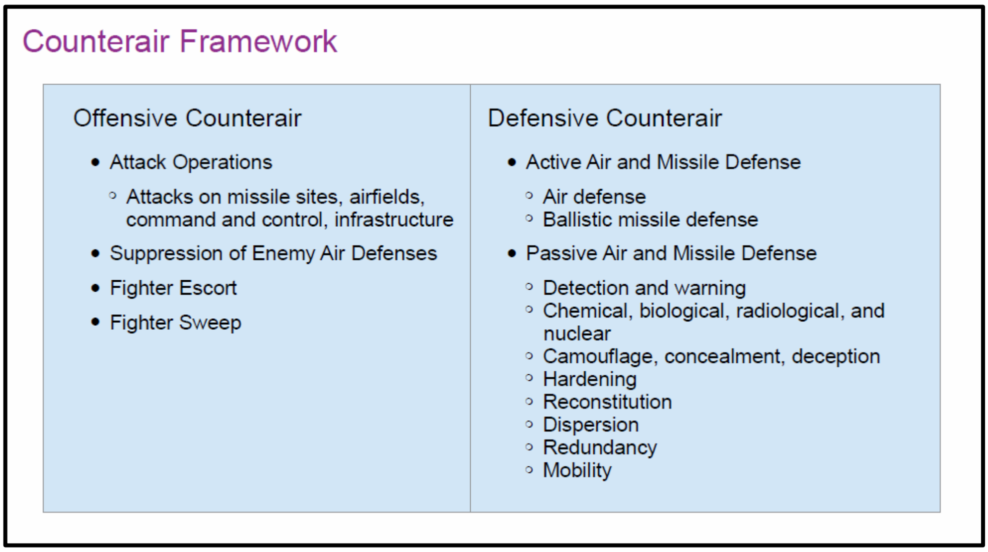
The pursuit of air superiority appears to be deeply embedded in the Western art of warfare. To challenge this approach would mean rethinking warfare itself, envisioning prolonged and bloodier conflicts that would inevitably call into question the notion of military commitment in Western societies.

## Achieving air superiority

The struggle for air superiority was a critical component of every major conflict of the twentieth century. Following an initial period from 1914 to 1940 characterized by individual heroism, experimentation, and prophecies, air combat evolved into an industrial-scale, high-intensity endeavor from the spring of 1941. The widespread deployment of SAMs during the Vietnam War, coupled with rapid technological advancements, particularly in onboard avionics and information warfare, fundamentally reshaped the nature of air warfare. In modern Western doctrine, air superiority is a joint line of operations, structured around two approaches: offensive and defensive.

52. S. Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle*, Princeton: Princeton University Press, 2006.

**Figure 2: USAF air superiority concept framework**




*Source: US Joint Publication 3-01, Countering Air and Missile Threats, April 21, 2017, pp. I-5, available at: https://irp.fas.org.*

## *A brief history of the quest for air superiority*

Armed forces first encountered air warfare, along with its principles and limitations, in the First World War. Throughout the conflict, air superiority on the Western Front frequently shifted between the Allies and the Germans. Technological mastery played a crucial role through aircraft performance. The Fokker Eindecker, the first aircraft equipped with synchronized machine guns capable of firing through its propeller, dominated the skies in the latter half of 1915, leading the British to speak of the "Fokker Scourge". The introduction of the highly maneuverable Nieuport 11, or Bébé Nieuport, during the Battle of Verdun helped the Allies regain the advantage—until the arrival of the German Albatros D.III, which outperformed its predecessors, leading to a technological arms race that culminated in the 1918 confrontations between the Spad XIII and the Fokker D.VII.

Other factors that contributed to air combat effectiveness include unit specialization and organizational structure. The Germans transitioned from Kek formations to Jasta squadrons and later Geschwadern, while the French developed flights, groups, and eventually an entire air division. These formations grew in scale over time. However, industrial capacity and the ability to mass-produce high-quality aircraft proved decisive. In this regard, air warfare in 1918 closely resembled ground warfare. General Carl Spaatz, commander of US Strategic Air Forces in Europe during the Second World War, summed up this reality when he stated: "Air control can be established by superiority in numbers, by better employment, by better equipment, or by a combination of these factors".

The Second World War reinforced these lessons and expanded air warfare into the electromagnetic domain with the development of radar and electronic countermeasures. Once again, it demonstrated that achieving air superiority demanded sustained and costly efforts against an adversary of comparable strength. The Germans, employing an inconsistent air strategy, failed to establish air superiority against the British during the Battle of Britain in the summer of 1940. Between February 1942 and April 1944, the Allies lost 10,338 aircraft and 55,097 personnel[53] in their strategic bombing campaign over Germany—a campaign that ultimately forced the Luftwaffe from the skies over Western Europe.

After 1945, the pursuit of air superiority often took place in conflicts constrained by political or strategic limitations. The USAF, for instance, faced significant operational constraints in the Korean War, as it was prohibited from striking Chinese airfields across the border—despite the fact that Communist fighter aircraft were launching from these bases to target American bombers and fighter-bombers. In Vietnam, the Americans, aiming to prevent escalation, refrained from striking North Vietnamese air bases until 1967—two years after the launch of Operation Rolling Thunder (1965–1968).

Simultaneously, new technologies and tactics emerged, complicating the struggle for air superiority. The Soviets furthered their love for artillery into the surface-to-air domain and developed successive generations of SAM batteries, specialized for different ranges and altitudes. These included the S-75 (SA-2 Guideline), S-200 (SA-5 Gammon), Kub (SA-6 Gainful), and Osa (SA-8 Gecko). When first deployed, these systems inflicted significant losses on American and Israeli air forces. During Operation Rolling Thunder (1965–1968), the USAF lost as many aircraft to SA-2 missiles (66) as it did in aerial engagements against MiGs (60).[54] On April 1, 1973, the Israeli Air Force had a total of 357 aircraft, yet in the opening days of the Yom Kippur War it struggled to penetrate Egyptian air defenses. Officially, the Israeli Air Force lost 102 aircraft in clashes with its Arab neighbors, primarily to SAMs.[55] It only regained air superiority over the Suez Canal sector after Israeli ground forces breached Egyptian lines, suffering heavy losses in the process, and neutralized the SA-6 batteries on the west bank of the canal with artillery strikes.

The West launched multiple industrial programs to mitigate the threat posed by Soviet SAM batteries. Electronic countermeasures were implemented alongside the development of specialized units equipped with F-105F Thunderchiefs and later F-4G Phantom aircraft, modified for electronic warfare and nicknamed “Wild Weasel”, to neutralize Soviet surface-to-air systems. These units initially employed AGM-45 Shrike

53. J. Ellis, *The World War II Data Book*, London: Aurum Press, 1993, p. 217.
54. USAF, *A Comparative Analysis of USAF Fixed-Wing Aircraft Losses in Southeast Asia Combat*, AFFDL-TR-77-115 (December 1977), Table A-1 (Part 1), p. 78.
55. L. Nordeen, *Fighters Over Israel*, New York: Orion Books, 1990, p. 146.

missiles, followed by AGM-78 Standard ARM missiles, which homed in on enemy radar emissions, tracking them to their source for destruction.

Conversely, in line with Corbett's "fleet-in-being" concept, some actors have favored limited, opportunistic actions against a dominant air force. The objective is to inflict consistent damage while minimizing their own losses. By preserving their own air assets, they ensure continued resistance and deny the adversary uncontested air superiority. The Royal Air Force applied this approach against the Luftwaffe during the Battle of Britain until early September 1940. Likewise, during the 1960s and 1970s, Vietnamese MiG pilots typically executed single-pass attacks on American strike packages before retreating to their air bases. In some cases, air commanders opt not to sortie their aircraft at all to preserve their combat capability. In 1999, recognizing their overwhelming disadvantage, Serbian forces refrained from directly contesting Western air power after the initial days of the Kosovo campaign. However, they continued flight operations, maintaining an enduring, albeit limited, threat—consistent with Corbett's fleet-in-being strategy. This forced Western planners to divert valuable resources from other tasks.

Nevertheless, the USAF was able to reassert its air superiority. Drawing on lessons from recent conflicts, mastering the complexities of electronic warfare, and deploying stealth aircraft designed to evade radar detection, the USAF formulated a highly effective doctrinal approach in the 1980s. During the 1991 Gulf War, it systematically dismantled Iraq's air defense network, targeting command infrastructure and neutralizing Iraqi aircraft both on the ground and in flight.[56]

This display of overwhelming air power left a lasting impression and established a doctrinal benchmark for Western air forces. Achieving air supremacy is feasible provided it is recognized as a strategic priority, endorsed at all levels, and allocated the necessary resources. Securing control of the air must be the first priority before conducting more complex military operations. This era of air supremacy is exemplified by the remarkable kill ratios of aircraft such as the F-15 and F-16, reported at approximately 103:0 and 76:1, respectively.[57]

After facing a significant challenge in the 1960s and 1970s from the development of Soviet ground-based air defense, Western air forces ultimately regained the initiative in the continuous struggle for air superiority. This success was driven by cutting-edge technological advancements, well-developed operational doctrines, and, notably, engagements against technologically inferior adversaries in conflicts of their own choosing.

56. R. P. Hallion, *Storm over Iraq: Air Power and the Gulf War*, Washington, DC: Smithsonian Institute, 1992.

57. J. Meilak, "The Combat Statistics for All the Aircraft Currently in Use", MiGFlug blog, undated, available at: https://migflug.com.

## *Achieving air superiority today: Offensive aspects*

To achieve air superiority, Western doctrine develops two key components, reflecting both the offensive and defensive aspects outlined above. The primary offensive mission set is known as offensive counter-air (OCA).[58] This concept was first introduced in 1943, in the US Army Field Manual FM 100-20, which detailed how American air forces envisioned air warfare following the US Army defeat at Kasserine. According to the manual, "Air superiority is best obtained by the attack on hostile airdromes, the destruction of aircraft at rest, and by fighter action in the air. This is much more effective than any attempt to furnish an umbrella of fighter aviation over our own troops".[59] Its objective is to neutralize the adversary's air capability within enemy territory by targeting both its aircraft and its GBAD.

The primary objective of this mission[60] is to neutralize the adversary's air assets on the ground, along with the critical infrastructure and support systems that enable their operation, and even the factories that produce them.[61] Destroying aircraft on the ground can have an immediate impact on the air battle,[62] but its effects may diminish over time if the adversary can replenish its fleet by manufacturing new aircraft in intact production facilities or by importing them from abroad. This tactical targeting is therefore particularly suited for short, rapid air campaigns or operations against adversaries with limited or nonexistent domestic aircraft production capabilities. Conversely, targeting enemy aircraft production plants or their critical supply chains as part of a broader strike campaign yields longer-term, structural effects that are more enduring.

Beyond aircraft, a wide range of targets can be engaged, including airfields, fuel storage sites, ammunition depots, ground-based air surveillance radars, electronic warfare systems, and C2 centers. Destroying these assets has both short- and medium-term effects, significantly restricting the enemy's ability to operate freely in the air domain.[63] Some targets, such as airfield runways, are relatively easy to repair and therefore require repeated strikes to remain neutralized.

The second objective of this offensive posture is to destroy enemy aircraft in the air. Two primary tactics are employed for this purpose: fighter sweeps, and escort missions that provide varying degrees of coverage for fighter-bombers. Historically, the debate over the operational effectiveness

58. Field Service Regulation FM 100-20, *Command and Employment of Air Power*, Washington, DC: War Department, United States Government Printing Office, July 21, 1943, p. 11, available at: www.ibiblio.org.
59. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–9.
60. Field Service Regulation FM 100-20, *Command and Employment of Air Power*, p. 11.
61. U.S. Air Force Doctrine Publication 3-01, *Counterair Operations*, June 15, 2023, p. 4, available at: www.doctrine.af.mil.
62. Ibid., pp. 26–27.
63. Ibid.

of sweeps versus escorts has been resolved in favor of the former. Tying fighters to a specific formation restricts their maneuverability and responsiveness in air combat, which demands flexibility and rapid execution. However, escort missions remain necessary until enemy aircraft are effectively neutralized, if only to minimize losses among strike aircraft.

Finally, the third objective of the OCA mission set is the neutralization or destruction of enemy ground-based air defenses, a task known as suppression of enemy air defenses (SEAD). To date, only the United States possesses the full spectrum of capabilities required for this mission, though about a dozen other Western air forces, along with Israel, can contribute in limited capacity. SEAD operations rely on a combination of decoys, radar and radio jamming, cyber attacks, and kinetic strikes using anti-radiation missiles, cruise missiles, long-range land or naval artillery, and special operations forces. It is important to note that SEAD missions can entail significant risk for the aircraft involved, particularly those without stealth capabilities, when engaging a modern, multi-layered IADS.

These three OCA components (strikes on ground-based assets, air-to-air combat, and SEAD) are complementary and, in principle, all essential in a high-intensity environment. In Ukraine, the failure of the Russian Aerospace Forces (VKS) to coordinate these OCA components effectively, or even to operate the SEAD mission by themselves, played a significant role in their failure at the operative level.[64] Their failure to establish air superiority in the early days of the invasion or in the subsequent months is partly to blame for the Russian Army's stalled ground offensives and the attrition suffered by its units.[65]

## *Achieving air superiority: Defensive aspects*

While OCA is the preferred mission of modern Western air forces—often operating at a great distance from their bases—its defensive counterpart, defensive counter air (DCA), is designed to protect military forces, civilian populations, infrastructure, and broader national interests from enemy air attacks. DCA missions are categorized into active and passive DCA.[66]

The purpose of active DCA is to destroy enemy forces attempting to penetrate airspace to attack friendly targets.[67] It relies on a fundamental triad of detection, identification, and engagement, facilitated by radar and other detection systems tailored to the protected airspace, a C2 network, and

64. J.-C. Noël, "Quelle campagne aérienne au-dessus de l'Ukraine? Premiers éléments de réflexion", *Briefing de l'Ifri*, Ifri, March 31, 2022, available at: www.ifri.org.
65. J. Bronk, "The Mysterious Case of the Missing Russian Air Force", *Commentary*, RUSI, February 28, 2022, available at: https://rusi.org.
66. J. R. Carter, *Airpower and the Cult of the Offensive*, College of Aerospace Doctrine, Research, and Education, Air University, October 1998, p. 9, available at: https://media.defense.gov.
67. Joint Doctrine Publication 0-30, *UK Air Power*, November 2022, p. 30, available at: https://assets.publishing.service.gov.uk.

kinetic engagement systems adapted to the specific threats. Fighter aircraft and GBAD form the core of these engagement capabilities.

Until recently, air defense fighters were capable of countering the majority of known aerial threats. They offer several key advantages, which have historically driven Western air forces to prioritize this capability.

Fighter aircraft play a crucial role in defense in depth because they can detect and engage threats well beyond the positions being defended, thereby providing additional reaction time for defending forces.[68] Tactically, airborne assets have the flexibility to reposition quickly in response to attacks launched along undefended axes. Fighters also offer a significant advantage in detecting low-flying conventional threats; unlike GBAD systems, they can overcome some of the limitations imposed by terrain and the Earth's curvature. Another key advantage of fighter aircraft is their ability to conduct visual identification of targets, allowing pilots to confirm threats and, in some cases, mitigate the risk of collateral damage or fratricide.[69] From a financial standpoint, air-to-air missiles are also significantly more cost-effective than their surface-to-air counterparts when comparing similar engagement ranges. For example, an AIM-120D missile costs just over $1 million, whereas a PAC-3 or SM-6 costs approximately $4 million.[70]

However, air defense fighters have a significant limitation: low persistence in the air. Maintaining continuous defensive coverage therefore requires a substantial commitment of both personnel and aircraft. The VKS, for example, have only a very limited capability of this kind in Ukraine; they typically sustain just two permanent combat air patrols (CAPs) composed of one or two aircraft each.[71] This limitation partly explains the very low number of air-to-air engagements observed in the theater since February 24, 2022.

The other key asset category to engage airborne threats is ground-based air defense, which encompasses a range of systems from anti-aircraft artillery to ballistic missile defense. These systems possess attributes that complement those of fighter aircraft. GBAD systems are particularly well suited for continuous operations and typically occupy a smaller footprint than an air base. Multiple types of systems, optimized for engagement at different altitudes, can be co-located in close proximity to provide mutual support and complicate enemy SEAD efforts. For example, a short-range SAM battery can protect a long-range system from the terminal dive of anti-radiation missiles, while the long-range system can draw away aircraft carrying SEAD weapons before they can fire. Finally, SAM batteries generally carry more munitions than a fighter patrol. This enables them to handle higher volumes of threats within a given time frame.

68. U.S. Air Force Doctrine Publication 3-01, p. 27.

69. NATO MC 362/1 *Rules of Engagement*, July 23, 2003.

70. "What the Patriot Missile System Can Do for Ukraine", *CBS News*, December 21, 2022, available at: www.cbsnews.com.

71. Research interview with Ukrainian army officers.

GBAD is therefore especially effective for protecting high-value, fixed targets against all types of threat. It is however less suited for defending a broad, continuous front. In Ukraine, on a front line stretching approximately 1,000 km, the Russian military has deployed around 1,000 individual elements (including radars, missile launchers, and command posts) as part of its GBAD system.[72] Despite this staggering number, the Russian IADS is far from being an impenetrable barrier.[73]

Over-reliance on GBAD can lead to much higher risks of collateral damage to civilian aircraft, as well as fratricide against friendly aircraft, and therefore necessitates strict rules of engagement.

To conclude this overview, let us recall the characteristics of passive DCA, which encompasses all means and measures intended to reduce the effectiveness of enemy air attacks that manage to evade fighter aircraft and SAM batteries.[74] These measures include camouflage, concealment, deception, hardening, emission control (EMCON), and the dispersal of critical assets. However, since the end of the Cold War, passive DCA has fallen somewhat into disuse among Western democracies, which have faced only modest threats of air attacks on their territory.

Today, the Western DCA model is built on a layered approach. It integrates air defense fighters deployed along the most likely avenues of enemy approach, supported by AWACS (Airborne Warning and Control System) aircraft and air-to-air refueling tankers, positioned ahead of a multi-layered GBAD system, which serves as a final protective barrier.

To conclude this first part, let us recall a few simple principles drawn from the experience of twentieth-century air warfare, which remain fundamental to the Western paradigm of air superiority:

- Achieving air superiority plays a critical role in the overall success of a joint operation, and its impact is greater when pursued offensively rather than maintained defensively.
- An offensive posture is more effective in securing air superiority than a purely defensive one.
- The optimal force allocation is the one that maximizes the effects of OCA operations, while assigning only the minimum necessary resources to DCA missions to protect military forces and other friendly centers of gravity.

Although the Western approach to air superiority has prevailed since 1991, it has come under increasing scrutiny in recent years. On the one hand, the ongoing conflict in Ukraine highlights the inability of both belligerents to

72. Research interview with Ukrainian army officers.
73. P. Grasser, "Des vides et des pièges: Défendre l'espace aérien russe", *Vortex*, No. 3, CESA, June 2022, pp. 163–177, available at: www.calameo.com.
74. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1–9.

establish control of the air. On the other hand, the West's potential adversaries, notably Russia and China, have responded to the 1991 demonstration of Western air dominance by reinforcing their anti-access/area denial (A2/AD) strategies. They are also actively developing capabilities meant to bypass Western air power and enable them to threaten the West's rear areas.

# Target & Threat – New threats to air superiority

Western air power faces two major challenges in a volatile and unpredictable international environment. The first is the growing capabilities of potential adversaries, particularly Russia and China, in the traditional domains of air superiority: air-to-air combat and GBAD.[75] The second is the heightened vulnerability of critical infrastructure essential to air superiority, such as air bases and IADS, to the development and proliferation of deep-strike capabilities. The increased quantity and performance of these systems allow adversaries to bypass conventional air power. These technologies, which are already being employed in Ukraine and the Middle East, are reinforcing anti-access strategies to the extent of significantly raising the cost of achieving air superiority.

## The air combat capabilities of potential adversaries

Between August 1990 and January 1991, the US-led coalition in Iraq was able to deploy nearly one million troops and 2,400 aircraft without encountering any opposition.[76] These forces intervened entirely on the coalition's terms, following political decision-making and a build-up of military forces.

In the event of a future confrontation, however, the United States' adversaries are no longer willing to grant such freedom of action. Their objective is to significantly degrade US military capabilities from the very outset of hostilities. This is to be achieved through strategies designed to prevent access to the theater of operations (anti-access) and to impede enemy operations within the theater if access is gained (area denial).[77]

An analysis of Russian and, above all, Chinese military capabilities today reveals a clear strategic intent: to acquire the capabilities needed to keep Western forces, particularly air forces, as far away from their territories as possible. To achieve this, they have developed a range of short-, medium-, and long-range missile systems capable of targeting command posts, air bases, ports, and logistical hubs. These are complemented by integrated,

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75. U.S. Air Force Doctrine Publication 3-01, p. 1.

76. *Gulf War Air Power Survey - Volume V: A Statistical Compendium*, Washington, DC: Library of Congress, 1993, available at: https://media.defense.gov.

77. A. Krepinevich, B. Watts, and R. Work, "Meeting the Anti-Access and Area-Denial Challenge", Center for Strategic and Budgetary Assessments, 2003, available at: https://csbaonline.org.

multi-layered GBAD systems and advanced fourth- and fifth-generation fighter aircraft, all intended to create an impenetrable defensive "bubble".

In this context, Western air power faces a critical challenge: How can these dense and sophisticated defenses be breached to restore freedom of action?

## *Russian and Chinese air contestation doctrines*

The Russian and Chinese air forces are structured around a model that differs significantly from that of Western air forces. Their respective strategies and doctrines, which are centered on contestation and circumvention, are essential to understanding the conceptual, technological, and capability gaps that separate them from the Western paradigm of airpower.

Since their inception, Soviet—and later Russian—air forces have been primarily designed and equipped to support ground forces[78] and defend Russia's vast territory. Current Russian doctrine, which is based on the assumption of a NATO military aggression, envisions the VKS confronting a series of large-scale air strikes in the opening hours of a conflict.[79] Aware of their structural inferiority in the air domain, the Russian high command aims to mitigate the impact of such strikes and prevent an early defeat through a strategy known as "active defense", with the goal of transitioning into a war of attrition that Russia believes it can conclude under favorable conditions.[80] The VKS view air superiority mainly from a defensive perspective that focuses on the density and performance of their GBAD systems[81] while attempting to degrade adversary air capabilities through long-range strikes on air power infrastructure. The VKS remain historically and politically subordinate to the Russian Ground Forces,[82] which themselves fall under the control of the broader security apparatus.[83] Their C2 structure is highly centralized and leaves minimal operational autonomy to tactical-level units. At present, the VKS are neither designed, structured, nor trained to achieve air superiority in a contested battlespace. Historically, the Soviet and later Russian military apparatus has tended to treat air forces as either short-range artillery (e.g., Su-25 with unguided bombs) or long-range artillery (e.g., Tu-22M, Su-34, Su-30MK2 and glide bombs and cruise missiles).

78. M. Benichou and X. Méal, "L'aviation de Staline au combat", in *Les Avions de combat soviétique de la Deuxième Guerre mondiale*, *Le Fana de l'Aviation*, hors-série No. 6, May 1997, p. 21.

79. M. Kofman et al., *Russian Military Strategy: Core Tenets and Operational Concepts*, CNA Research Memorandum, Center for Naval Analyses, August 2021, pp. 21–23, available at: www.cna.org.

80. Ibid., p. 14.

81. T. Withington, "Defending Mother Russia's Skies", *Commentary*, RUSI, July 13, 2022, available at: https://rusi.org.

82. J.-C. Noël, "Quelle campagne aérienne au-dessus de l'Ukraine? Premiers éléments de réflexion", op. cit., pp. 6–7.

83. S. M. Wiswesser, "Russian VKS Operational Planning for Ukraine, Hybrid War, and the Role of the Russian Special Services", in *The Air War in Ukraine: The First Year of Conflict*, pp. 30–65.

The Chinese People's Liberation Army (PLA) interprets the concept of air superiority using the term *zhikongquan* (制空权), meaning "control of the air".[84] It envisions the attainment of air superiority as a three-pronged, progressive process of kinetic operations, electronic and cyber warfare, and information warfare.[85] This concept is applied in a localized and time-limited manner, with a strong emphasis on denying the adversary control of the air, primarily through a dense IADS and strikes against enemy air bases.[86] The organizational structure of the PLA Air Force (PLAAF) is entirely modeled on that of the ground forces, although the PLAAF gained political autonomy during the 2004 reforms.[87] Unlike the VKS, the PLAAF has initiated a process of decentralizing tactical command and granting greater authority to pilots at the expense of control centers.[88]

## Combat aviation of the West's potential adversaries

Since the collapse of the Soviet Union, Western combat aircraft have faced adversary fighter aircraft in only two instances: Iraq in 1991 and the Kosovo conflict in 1999. In both cases, the opposing air forces were weak in terms of numbers, technology, and doctrine, which reinforced NATO air forces' sense of superiority in air combat.

However, since the early 2000s, the West's main potential adversaries, chiefly China and Russia, have pursued a significantly more ambitious path in developing capabilities in this domain, focusing primarily on two key areas: fighter aircraft and air-to-air weaponry.

### Russian air-to-air and SEAD capabilities

Analyzing a potential adversary's air combat capabilities is essential for evaluating the relevance of Western force structure and doctrine. Only through threat assessment can appropriate tactical, doctrinal, and capability-based responses be developed.

Russia continues to make incremental improvements to its fourth-generation Sukhoi Su-27 Flanker variants, whose engine performance, maneuverability, range, and payload capacity make them well-suited for air combat. The VKS mainly use the Su-35S Flanker-M for offensive air

84. D. Solen, "The PLA Reconceptualizes Control of the Air", *China Brief*, Vol. 23, No. 13, The Jamestown Foundation, July 21, 2023, available at: https://jamestown.org.
85. Ibid.
86. *The Science of Military Strategy*, National Key Discipline Theory Works of National Defense University, National Defense University Press, edition updated in 2020 and translated by the China Aerospace Studies Institute, January 2022, available at: www.airuniversity.af.edu.
87. N. Rabé, "L'organisation de l'armée de l'Air chinoise", *Vortex,* No. 5, CESA, June 2023, pp. 125–128, available at: www.calameo.com.
88. A. Yanan Zhang, "L'évolution de la doctrine chinoise depuis la guerre du Golfe (1991). Quelles implications pour l'armée de l'Air?", *Vortex,* No. 5, CESA, June 2023, p. 178, available at: www.calameo.com.

superiority missions.[89] By contrast, the MiG-29SMT fleet, which is limited by significant deficiencies in range, onboard avionics, and weapons integration, serves mainly as a training aggressor platform for other units[90] and is reportedly being transferred to North Korea.[91]

The VKS operate approximately 90 MiG-31BM Foxhound aircraft.[92] These are 1980s-era interceptors upgraded to integrate with the Russian IADS and to detect and engage targets at extended ranges while remaining within the protection envelope of the IADS.[93] These aircraft serve as high-altitude quarterbacks but are not suited for offensive air superiority missions.

Since 2002, Russia has also been developing the Su-57 Felon, a fifth-generation stealth fighter derived from the Su-27. While it features a reduced RCS, its low observability is significantly less advanced than that of its US counterparts (the F-22 and F-35).[94] Only about 20 production units have been delivered since 2020,[95] and operational deployment remains limited.[96] Production has continued at a very slow pace, particularly since the onset of the invasion of Ukraine. Development has been hampered not only by issues with critical subsystems, including the engines,[97] but also by Western sanctions that have constrained access to electronic components.[98] The VKS have placed an order for 76 Su-57s, scheduled for delivery by 2028.[99] However, Russia's current economic and military situation[100] raises doubts about the defense industry's capacity to sustain a fifth-generation fighter program while also maintaining production of the fourth-generation platforms needed for ongoing operations. The Su-75 Checkmate program is expected to face similar difficulties, notwithstanding the very ambitious development timeline typical of Russian official announcements.[101]

89. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", *Whitehall Report*, RUSI, October 30, 2020, pp. 15–20, available at: https://static.rusi.org.

90. Ibid., pp. 24–26.

91. T. Newdick, "Russia Giving North Korea MiG-29s and Su-27s Isn't That Straightforward", *The War Zone*, December 10, 2024, available at: www.twz.com.

92. *Military Balance 2024*, IISS, February 12, 2024, p. 200.

93. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., pp. 26–29.

94. VuVuZela (pseudo), "Su-57 Radar Scattering Simulation", September 26, 2022, available at: https://basicsaboutaerodynamicsandavionics.wordpress.com.

95. *Military Balance 2025*, op. cit.

96. S. D'Urso, "First Serial Production Su-57 Felon Delivered to the Russian Aerospace Forces", *The Aviationist*, December 30, 2020, available at: https://theaviationist.com.

97. Ibid.

98. S. Atlamazoglou, "Russia's Su-57 Felon Fighter Nightmare Might Not Be 'Solvable'", *The National Interest*, August 28, 2024, available at: https://nationalinterest.org.

99. "Russia's Su-57 Outshines US Fifth-generation Fighters, Says Expert", *TASS*, October 21, 2021, available at: https://tass.com.

100. R. Bauer and P. A. Wilson, "Russia's Su-57 Heavy Fighter Bomber: Is It Really a Fifth-Generation Aircraft?", *Commentary*, RAND, August 17, 2020, available at: www.rand.org.

101. J. V. Parachini and P. A. Wilson, "Is Russia's Su-75 'Checkmate' Aircraft a Case of Vapor Marketing?", Commentary, RAND, January 6, 2022, available at: www.rand.org.

The withdrawal of funding by the United Arab Emirates[102] could delay or potentially derail the program entirely.

### Table 2: VKS fighter aircraft contributing to air superiority, 2024

| Type | Number | Contribution |
|---|---|---|
| Su-27S (Flanker-B) | 27 | DCA (obsolete) |
| Su-27SM (Flanker-J) | 47 | DCA |
| Su-30SM (Flanker-H)[103] | 80+ | DCA - OCA - SEAD |
| Su-34 (Fullback) | 124+ | OCA - SEAD |
| Su-35S (Flanker-M) | 111+ | DCA - OCA - SEAD |
| MiG-29S (Fulcrum-A and -C) | 70 | DCA (obsolete) |
| MiG-29SMT (Fulcrum) | 14 | DCA |
| MiG-31BM (Foxhound-C) | 88 | DCA |
| Su-57 (Felon) | 12+ | DCA - OCA |

*Sources: Military Balance 2024, IISS, February 12, 2024; J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", Whitehall Report, RUSI, October 30, 2020.*

Russia is currently testing a collaborative combat drone, the S-70 Okhotnik-B.[104] However, the limitations of the Russian aeronautical industry, including in the domains of automation and stealth technology, as well as its apparent lag behind comparable Western unmanned combat aerial vehicle (UCAV) programs, seem to rule out an operational stealth UCAV capability within the next decade.[105]

In the field of air-to-air missiles, Russia has not achieved any major breakthroughs since the 1990s. For medium-range engagements, the VKS primarily rely on the R-77-1 (AA-12B Adder),[106] an active radar-guided missile with performance inferior to that of the American AIM-120C AMRAAM, along with its more recent variant, the K-77M (AA-12C). The introduction of the R-37M (AA-13 Axehead), a very long-range air-to-air missile, generated tactical surprise in the skies of Ukraine. For short-range engagements, the VKS continue to field the R-73 (AA-11A Archer) and its upgraded version, the R-74M (AA-11B), both of which are technologically

102. B. Nikolov, "UAE Appears to Have Stopped Funding the Sukhoi Su-75 Project", *Bulgarian Military*, October 2, 2022, available at: https://bulgarianmilitary.com.
103. The 19 Su-30M2s, derived from the Su-30MKK export version developed for China, are not included because they are used as operational conversion units.
104. S. D'Urso, "The Russian S-70 Okhotnik UCAV Struck Ground Targets with Unguided Bombs During Weapons Testing", *The Aviationist*, January 14, 2021, available at: https://theaviationist.com.
105. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., pp. 33–34.
106. Ibid., p. 14.

inferior to their Western counterparts—particularly because of the lack of imaging infrared seekers—and have significantly lower kinematic performance compared to the MICA IR, IRIS-T, or AIM-9X.[107]

For SEAD, the VKS use the Kh-31P (AS-17 Krypton) supersonic anti-radiation missile,[108] which replaced the older Kh-58 (AS-11 Kilter), a Soviet derivative of the French AS-37 Martel. Both missile systems, based on 1980s-era technology, have been used in combat operations since the 2008 conflict in Georgia and more recently in Ukraine since 2022, with mixed operational results. Their limited effectiveness can be attributed to their technological obsolescence, the lack of a coherent SEAD doctrine and experienced pilots in the VKS, as well as the effectiveness of Ukrainian IADS countermeasures.[109]

Indeed, the primary weakness of Russian combat aviation lies not in technology, but in doctrine and human factors. The training of Russian fighter pilots remains below NATO standards, both qualitatively, with relatively simple training missions and irregular air-to-air refueling, and quantitatively, with a low number of flight hours.[110] Russian tactical procedures continue to reflect a rigid command structure with heavy reliance on centralized control, lacking the coherent operative framework found in Western air command systems. Numerous encounters between NATO air forces and the VKS have revealed widespread indiscipline among Russian fighter pilots—implicitly sanctioned or not by their chain of command—as well as a persistent inability to plan and execute the complex air operations required to achieve air superiority, which, in any case, are absent from their doctrinal framework.[111]

Overall, the air combat capability of the VKS remains highly limited and primarily defensive in nature. Penetrating defended airspace to establish air superiority appears beyond their operational reach. Although the Ukrainian Air Force has lost several outdated MiG-29S and Su-25 aircraft that were caught off guard by Russian R-77-1 and R-37M air-to-air missiles,[112] its resilience in the face of clear numerical and technological inferiority reflects

107. D. Barrie, "Moscow Dusts Off Decades-delayed 'Dogfight' Missile", *Military Balance Blog*, IISS, February 24, 2021, available at: www.iiss.org.

108. C. Kopp, "Soviet/Russian Tactical Air to Surface Missiles", *Technical Report* APA-TR-2009-0804, Air Power Australia, August 2009, updated April 2012, available at: www.ausairpower.net.

109. I. Williams, "Putin's Missile War: Russia's Strike Campaign in Ukraine", CSIS, May 2023, p. 29, available at: www.csis.org; J.-C. Noël, "Quelle campagne aérienne au-dessus de l'Ukraine? Premiers éléments de réflexion", op. cit., pp. 9–10; J. Bronk, "How Ground-based Air Defences Have Shaped the Air War over Ukraine", op. cit., pp. 137–167.

110. J. Bronk, "The Mysterious Case of the Missing Russian Air Force", *Commentary*, RUSI, February 28, 2022, available at: https://rusi.org.

111. S. D'Urso, "Russian Pilot Deliberately Shot At RAF RC-135 Last Year", *The Aviationist*, September 14, 2023, available at: https://theaviationist.com; R. Browne and B. Starr, "Russian Fighter Jet Makes 'Unsafe' Intercept of US Aircraft", *CNN*, September 8, 2016, available at: https://edition.cnn.com; "Police du ciel en mer Baltique" [Dans le viseur #66], Le Collimateur podcast, May 10, 2024, available at: https://lerubicon.org; J. Bronk, "Is the Russian Air Force Actually Incapable of Complex Air Operations?", *RUSI Defence Systems*, No. 24, RUSI, March 4, 2022, available at: https://rusi.org.

112. J. Bronk, N. Reynolds, and J. Watling, "The Russian Air War and Ukrainian Requirements for Air Defence", *Special Resources*, RUSI, November 7, 2022, pp. 6–20, available at: https://rusi.org.

both the adaptability and tactical ingenuity of Ukrainian pilots[113] (significantly supported by US intelligence capabilities) and the shortcomings of Russian combat aviation, despite it being the third-largest fighter fleet in the world.

## Chinese air-to-air and SEAD capabilities

The PLA fighter fleet, which was historically based on a large inventory of license-produced Soviet aircraft primarily dedicated to the air defense of Chinese territory, has undergone a rapid modernization effort since the wake-up call of the First Gulf War.[114] The PLA is now replacing its third-generation aircraft with a modern force structure built around a high-low mix of fourth- and fifth-generation platforms, featuring strong offensive capabilities but limited long-range power projection.[115]

The backbone of the PLAAF is its fleet of fourth-generation fighters. The J-10 Firebird, whose design draws heavily on the Israeli LAVI—an unfortunate clone of the F-16—represents the lower tier of this mix.[116] Its development has been instrumental in advancing China's aeronautical industry and reflects a consistent qualitative evolution: The J-10C variant features combat capabilities (active electronically scanned array [AESA] radar, infrared search and track [IRST] system, data link, etc.) that are comparable to those of the Rafale F3R or the F-16V Viper.[117]

The middle segment of the mix consists of numerous Chinese derivatives of the Su-27 Flanker, operated by both the PLAAF and the Chinese Navy.[118] Like the J-10, these Chinese Flankers undergo incremental upgrades during production, with the latest versions equipped with domestically developed sensors, mission systems, and weapons that are reportedly of higher quality than their Russian counterparts.[119]

113. D. Henriksen and J. Bronk (eds.), *The Air War in Ukraine: The First Year of Conflict*.
114. A. Yanan Zhang, "L'évolution de la doctrine chinoise depuis la guerre du Golfe (1991). Quelles implications pour l'armée de l'Air?", op. cit., p. 166 and pp. 161–163.
115. *Military Balance 2024*, op. cit., p. 260.
116. C. Kopp, "Chengdu J-10", *Technical Report* APA-TR-2007-0701, Air Power Australia, April 2012, available at: www.ausairpower.net.
117. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., pp. 39–41.
118. C. Kopp, "PLA-AF and PLA-N Flanker Variants", *Technical Report* APA-TR-2012-0401, Air Power Australia, May 2012, available at: www.ausairpower.net.
119. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., pp. 37–39.

## Table 3: Evolution of the PLAAF fighter fleet contributing to air superiority

| Type | Fleet 2004 | Fleet 2024 | Contribution |
|---|---|---|---|
| **A-50 (Fantan)** | 300 | 0 | Ground attack |
| **J-6 (Farmer)** | 350 | 0 | Ground attack |
| **J-7 (Fishcan)** | 674 | 289 | DCA |
| **J-8II (Finback)** | 184 | 50 | DCA |
| **J-10 (Firebird)** | 0 | 580 | DCA - OCA |
| **J-11A (Su-27SK Flanker-B)** | 100 | 95 | DCA |
| **J-11B/BS (Flanker-L)** | 0 | 150 | DCA – OCA |
| **Su-30MKK/MK2 (Flanker-G)** | 58 | 97 | DCA - OCA - SEAD |
| **J-16 (Flanker-N)** | 0 | 280 | DCA - OCA - SEAD |
| **J-16D (Flanker- ?)** | 0 | 12 | SEAD - EA |
| **Su-35 (Flanker-M)** | 0 | 24 | DCA - OCA - SEAD |
| **J-20A (Fagin)** | 0 | 200+ | DCA - OCA |

*Sources: Military Balance 2004, IISS, October 2003; and Military Balance 2024, IISS, February 12, 2024.*

Unlike Russia, China has successfully entered the fifth-generation fighter club, having deployed a fleet of operational J-20s roughly equivalent in size to the French fighter fleet—and it continues to grow and improve.[120] While the J-20's stealth characteristics remain significantly inferior to those of American fighters,[121] the aircraft nonetheless presents a challenge in terms of detection and engagement range for Western fourth-generation fighters. It also poses a threat to critical support aircraft (AWACS and tankers) that are essential to US operations in the Pacific. The J-20 is designed primarily to support China's anti-access strategy in the South China Sea by threatening these high-value airborne assets (HVAAs) without necessarily having to directly engage American fighters.[122] Since 2011, China has also been developing the FC-31/J-35, a light stealth fighter inspired by the American F-35, intended for both its navy and air force. On December 26, 2024, the anniversary of Mao Zedong's birth, it unveiled two new stealth fighter prototypes, the J-36 and J-50, whose precise roles remain undetermined.[123]

120. E. Tirk, "Status of 41st Aviation Brigade Transition to the J-20", China Aerospace Studies Institute, Department of the Air Force, April 2024, available at: www.airuniversity.af.edu.
121. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., pp. 41–44.
122. G. Barber, "The Role of the J-20 in Chinese Air Power", *Vortex*, No. 5, CESA, June 2023, pp. 181–193, available at: www.calameo.com.
123. P. Satam and S. D'Urso, "China's J-35A Stealth Fighter to be Officially Unveiled at Zhuhai Air Show", *The Aviationist*, November 5, 2024, available at: https://theaviationist.com; T. Newdick and T. Rogoway, "China Stuns with Heavy Stealth Tactical Jet's Sudden Appearance (Updated)", *The War Zone*,

On the combat drone front, China is actively developing the GJ-11, a stealth UCAV with internal weapons bays, which also appears to be undergoing adaptation for use by its naval aviation forces.[124] By contrast, the Dark Sword—a concept for a stealth, supersonic, hybrid-powered loyal wingman combat drone—has not been publicly referenced since 2018, and the program has likely been canceled in favor of the FH-97A, which Western intelligence has been aware of since at least 2021 and which was publicly unveiled at the 2024 Zhuhai Airshow.[125]

Unlike their Russian counterparts, Chinese air-to-air weapons are advancing rapidly. They are also moving away from reliance on Soviet and Western technologies. Until the early 2010s, China focused on copying or upgrading foreign missile designs—as with the PL-8, a copy of Israel's Python-3[126]—which helped the Chinese arms industry build technical expertise. Today, China is developing a domestic family of air-to-air missiles with performance levels comparable to those of Western systems:

- the dual-pulse PL-15, reportedly offering greater range than the AIM-120D;[127]
- the PL-17, developed to engage HVAAs at extended ranges—similar in concept to the Russian R-37M—with a maximum range significantly exceeding that of the European Meteor, though its conventional rocket propulsion limits its kinematic performance against fighter aircraft;[128]
- and the PL-21, a long-range ramjet-powered missile comparable to the Meteor, though its exact performance characteristics remain unknown.[129]

China's SEAD capability is primarily oriented toward passive anti-ship operations. The only dedicated SEAD munitions fielded by the PLA are the Russian Kh-31P and its Chinese derivative, the YJ-91, which are operated by the Chinese Navy on Su-30MK2 and JH-7A aircraft, as well as on PLAAF Flanker variants.[130] Chinese interest in traditional SEAD appears limited, as

December 26, 2024, available at: www.twz.com; T. Newdick, "Yes, China Just Flew Another Tailless Next-Generation Stealth Combat Aircraft", *The War Zone*, December 26, 2024, available at: www.twz.com.

124. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", p. 55; T. Newdick, "Mockup of Chinese Stealth Drone Appears on Full-Size Aircraft Carrier Test Rig", *The War Zone*, December 19, 2023, available at: www.twz.com.

125. T. Rogoway, "Image of China's Stealthy 'Dark Sword' Fighter-Like Combat Drone Emerges", *The War Zone*, June 5, 2018, available at: www.twz.com; J. Saballa, "China Develops Own 'Loyal Wingman' to Rival US", *The Defense Post*, December 16, 2024, available at: https://thedefensepost.com; "Dark Sword (An-Jian/Anjian)", *Global Security*, undated, available at: www.globalsecurity.org.

126. T. Newdick, "A Guide to China's Increasingly Impressive Air-To-Air Missile Inventory", *The War Zone*, September 1, 2022, available at: www.twz.com.

127. P. Wood, D. Yang, and R. Cliff, "Air-to-Air Missiles: Capabilities and Development in China", China Aerospace Studies Institute, November 2020, p. 39, available at: www.airuniversity.af.edu.

128. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", p. 36.

129. P. Wood, D. Yang, and R. Cliff, "Air-to-Air Missiles: Capabilities and Development in China", p. 40.

130. D. M. Gormley, A. S. Erickson, and Jingdong Yuan, "A Low-Visibility Force Multiplier: Assessing China's Cruise Missile Ambitions", Center for the Study of Chinese Military Affairs, Institute for National Strategic Studies, 2014, p. 22, available at: https://inss.ndu.edu.

the US bases that could be potential targets for Beijing are located beyond the reach of China's limited power projection capabilities, particularly with respect to air-to-air refueling.[131] Instead, China's anti-access strategy relies on ballistic and cruise missile systems to strike those targets.[132]

The skill level of Chinese aviators is difficult to assess. Until the early 2010s, the PLAAF remained a highly centralized force with minimal initiative allowed at the pilot level,[133] following a force employment doctrine similar to that of the VKS and marked by the same issues of indiscipline and lack of professionalism.[134] The PLAAF has not had any combat experience since 1979 and only recently began participating in international exercises.[135] However, there are several signs that the PLA is steadily improving in this domain,[136] starting with its aggressive recruitment of former Western fighter pilots.[137] The scale and complexity of Chinese air incursions into Taiwan's Air Defense Identification Zone (ADIZ) also reflect growing competence in air mission coordination.[138]

Finally, to conclude this overview of the air threat, it is worth mentioning the increasing adoption of stealth—at least low observable—technologies by countries that have gained prominence in the arms market since the 2010s, such as Turkey[139] and South Korea.[140] In the coming years, third-party states may acquire stealth combat aircraft or related technologies from Russia or China. Although these platforms would likely be inferior in quality to American aircraft, they could still pose a significant tactical challenge to those Western air forces that remain limited to fourth-generation platforms. Algeria has reportedly placed an order for a batch of Su-57s from Russia.[141] In the European theater, Russia's air-to-air and SEAD capabilities remain well below NATO standards. As a result, air-to-air combat, when considered in isolation, is not currently viewed as a major concern by French military leadership.

131. J. G. McPhilamy, "Air Supremacy: Are the Chinese Ready?", *Military Review*, January–February 2020, pp. 58–59, available at: www.armyupress.army.mil.
132. E. Heginbotham et al., "The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power", RAND, 2015, pp. 46–70, available at: www.rand.org.
133. The author's personal experience of an information flight by a Chinese Mirage 2000 pilot in 2010.
134. B. Gertz, "The Last Flight of Wang Wei", *Air & Space Forces Magazine*, July 1, 2001, available at: www.airandspaceforces.com.
135. A. Vidal Ribe and J. Dempsey, "More Than a Mirage: UAE Combat Aircraft in China", *Military Balance Blog*, IISS, July 22, 2024, available at: www.iiss.org.
136. E. Tegler, "China Is Finally Seeking Fighter Pilots with College Degrees", *Forbes*, September 27, 2023, available at: www.forbes.com.
137. B. Bennett, "U.S. Cracks Down on Former 'Top Gun' Pilots Found to Be Training China's Air Force", *Time*, June 5, 2024, available at: https://time.com.
138. Lee Jyun-yi, Sheu Jyh-shyang, and Shu Hsiao-huang, "China's Incursion into Taiwan's 'Air Defense Identification Zone' and Its Implications for Regional Security", *Vortex*, No. 5, CESA, June 2023, pp. 309-322, available at: www.calameo.com.
139. J. Trevithick, "Our First Full Look At Turkey's New TF-X Stealthy Fighter", *The War Zone*, March 17, 2023, available at: www.twz.com.
140. T. Newdick, "South Korea's KF-21 Next Generation Fighter Begins Tanker Trials", *The War Zone*, March 19, 2024, available at: www.twz.com.
141. M. Rojoef, "Russia Inks First Su-57 Supersonic Fighter Jet Export Deals", *The Defense Post*, November 14, 2024, available at: https://thedefensepost.com.

However, this perception could shift rapidly if a breakthrough in artificial intelligence (AI)—which has yet to be observed—were to enhance the VKS's effectiveness in electronic warfare or collective tactics.[142]

On the other hand, conducting air-to-air combat within the engagement zone of an adversary's IADS presents a significant tactical and capability challenge, one that requires a critical assessment of the GBAD capabilities of the West's potential adversaries.

## *The state of play and breakthroughs in the IADS threat*

Beyond the air-to-air threat, which is significant in the medium term in the case of China and more limited in the case of Russia, the primary challenge facing Western air forces in the battle for control of the air is the Russian surface-to-air inventory, the growing sophistication of Chinese manufacturers, and the proliferation of these systems in states potentially hostile to Western interests. GBAD systems, which form the cornerstone of the Russian air power strategy,[143] are designed to degrade rather than destroy Western air capabilities.[144] They present three key characteristics that underscore the scale of the challenge they pose to achieving air superiority: the increased individual performance of weapons systems; their high mobility; and their deployment in redundant, mutually supporting layers.

### Increased performance

Since the 1990s, the performance of Russian and Chinese GBAD systems has advanced far more rapidly than that of traditional Western countermeasures, such as US anti-radiation weapons.

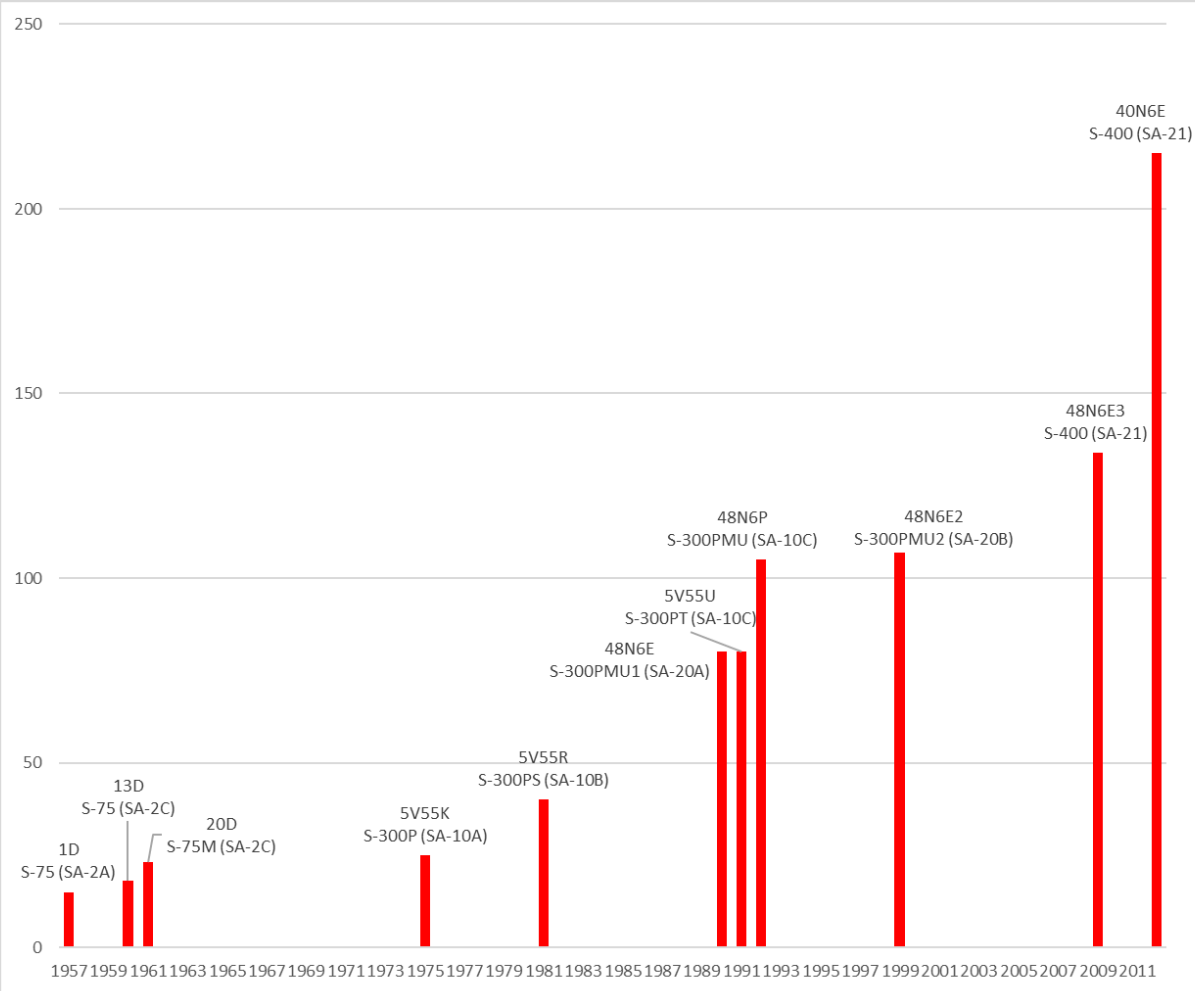
The engagement ranges of long-range SAMs in the S-300[145] (SA-10 Grumble and SA-20 Gargoyle), HQ-9,[146] S-400[147] (SA-21 Growler), and S-500[148] (SA-31) families continue to increase. These ranges, however, should not be interpreted as absolute exclusion zones, as the engagement

142. Research interview with a general officer of the French Air and Space Force.
143. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", *Occasional Paper*, RUSI, January 15, 2020, p. 15, available at: https://rusi.org.
144. Research interview with a retired general officer of the French Air and Space Force.
145. C. Kopp, "Almaz S-300P/PT/PS/PMU/PMU1/PMU2 Almaz-Antey S-400 Triumf SA-10/20/21 Grumble/Gargoyle", *Technical Report* APA-TR-2006-1201, Air Power Australia, April 2012, available at: www.ausairpower.net.
146. C. Kopp, "CPMIEC HQ-9/HHQ-9/FD-2000/FT-2000 Self Propelled Air Defence System", *Technical Report* APA-TR-2009-1103, Air Power Australia, April 2012, available at: www.ausairpower.net.
147. C. Kopp, "Almaz-Antey 40R6/S-400 Triumf Self Propelled Air Defence System/SA-21", *Technical Report* APA-TR-2009-0503, Air Power Australia, April 2012, available at: www.ausairpower.net.
148. C. Kopp, "Almaz-Antey S-500 Triumfator M Self Propelled Air/Missile Defence System/SA-X-NN", *Technical Report* APA-TR-2011-0602, Air Power Australia, April 2012, available at: www.ausairpower.net.

envelope of a SAM system is three-dimensional and often presents gaps that can be exploited by fighter aircraft or air- and ground-launched weapons.

Nonetheless, even when positioned tens of kilometers behind the front line, beyond the range of enemy artillery, these systems offer sufficient standoff range to complicate the approach of strike aircraft. They also force Western air-to-air refueling and airborne support platforms to operate at the outer limits of their effective range in contested airspace.[149] That said, the engagement range of such systems, constrained by the laws of physics, appears to be approaching a ceiling.[150]

**Graph 1: Evolution of ranges, in nautical miles (NM), of Soviet and Russian long-range surface-to-air missiles**

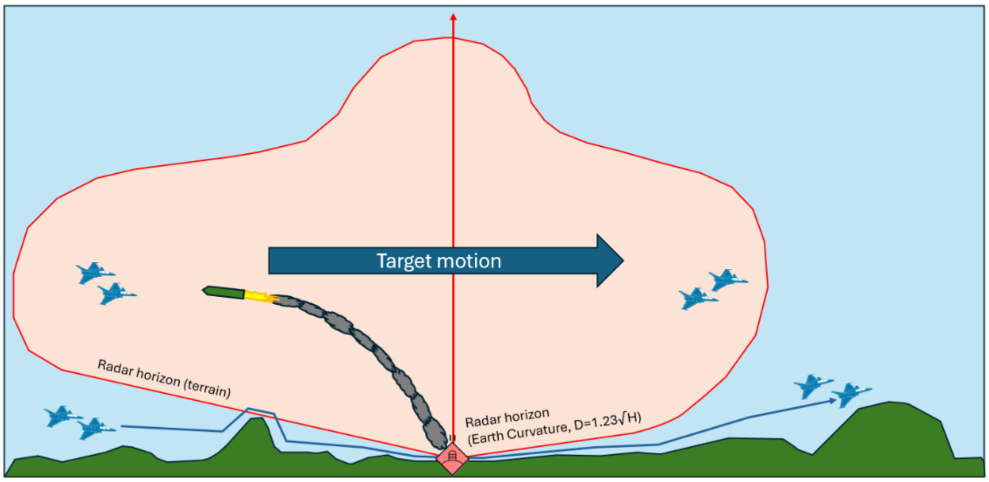



*Sources: C. Kopp, "Almaz S-75 Dvina/Desna/Volkhov Air Defence System / HQ-2A/B / CSA-1 / SA-2 Guideline", Technical Report APA-TR-2009-0702, Air Power Australia, April 2012; C. Kopp, "Almaz S-300P/PT/PS/PMU/PMU1/PMU2 Almaz-Antey S-400 Triumf SA-10/20/21 Grumble/Gargoyle", Technical Report APA-TR-2006-1201, Air Power Australia, April 2012; and J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", Occasional Paper, RUSI, January 2020.*

149. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit., p. 15.
150. Research interview with a French Air and Space Force officer specializing in GBAD systems.

This trend also extends to medium-range tactical systems in the Buk family[151] (SA-11 Gadfly, SA-17 Grizzly, and SA-27 Gollum) and the HQ-16, whose engagement envelopes in 2025 are comparable to those of long-range systems from the 1990s.

**Figure 3: Generic firing range of a surface-to-air missile (vertical cross-section) as a function of the axis of movement of the target and low-altitude penetration profile**




*Source: Author's operational experience.*

In addition to their kinetic capabilities, the radar performance, fire-control systems, and networked integration of Russian and Chinese GBAD systems are steadily improving. AESA radar technology is becoming standard for fire-control radars,[152] while bistatic surveillance radars and systems operating outside conventional frequency bands are increasingly employed to counter US VLO technology—exemplified by the Russian Struna-1[153] and Nebo-M,[154] as well as the latter's Chinese derivative, the JY-27. While these systems are widely believed to be capable of detecting stealth aircraft,[155] this detection does not yet enable an effective kill chain because VHF-band radars do not provide tracking data with sufficient precision for SAM target designation.[156] Concurrently, Russia and China are developing over-the-horizon (OTH) radar technologies capable of detecting targets

151. C. Kopp, "NIIP 9K37/9K37M1/9K317 Buk M1/M2 Self Propelled Air Defence System/SA-11/17 Gadfly/Grizzly", *Technical Report* APA-TR-2009-0706, Air Power Australia, April 2012, available at: www.ausairpower.net.

152. C. Brustlein, É. Tenenbaum, and É. de Durand, *La Suprématie aérienne en péril: Menaces et contre-stratégies à l'horizon 2030*, op. cit., pp. 75–78.

153. M. Gyűrösi, "NNIIRT 52E6MU Struna-1MU/Barrier E Bistatic Radar", *Technical Report* APA-TR-2009-1101, Air Power Australia, April 2012, available at: www.ausairpower.net.

154. J.-C. Noël, M. Paglia, and É. Tenenbaum, "Les armées françaises face aux menaces anti-aériennes de nouvelle génération", *Focus stratégique*, No. 86, Ifri, December 2018, p. 14, available at: www.ifri.org.

155. K. Zikidis, A. Skondras, and C. Tokas, "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies", op. cit., pp. 153–154.

156. "The S-400 Myth: Why Russia's Air Defense Prowess is Exaggerated", *Sandboxx*, Airpower, July 21, 2022, available at: www.sandboxx.us.

despite the Earth's curvature—such as the Russian Konteyner and Rezonans-NE,[157] and the Chinese Type SLR-66.

The actual performance of Russian radar systems still appears to be inferior to that of their Western counterparts and was shown to be highly susceptible to fratricidal jamming by Russian forces during the early stages of the invasion of Ukraine.[158] By contrast, China has replaced its imported Russian surveillance and fire-control radars with domestically produced components, which are reportedly of higher quality.[159]

This technological evolution now gives a credible self-defense capability against incoming air-launched weapons to modern Russian and Chinese GBAD systems, as observed in Ukraine. This development partially undermines the traditional SEAD employment concept, which relies on a limited number of anti-radiation or cruise missiles to degrade the adversary's IADS. High-speed anti-radiation missiles (HARMs) can now be intercepted either by the very systems they are targeting or by short-range point-defense systems protecting them, such as the Pantsir-S1[160] (SA-22 Greyhound). This anti-missile capability is further supported by the substantial missile load of Russian air defense units: S-400 battalions, for instance, carry between 48 and 192 missiles depending on the type. All these factors advocate for a reassessment of SEAD/DEAD tactics and leave few kinetic alternatives beyond saturation attacks by sheer numbers or extremely high-performance missile systems with at least high supersonic speed and terminal maneuverability.

## Mobility and redundancy

However, despite the increased performance of its SAM systems, the sophistication of US anti-radiation weapons and Western low-altitude penetration capabilities (particularly cruise missiles) have compelled Russia to invest heavily in enhancing the resilience of its GBAD complex. This has been achieved primarily through improved technical mobility, a lesson learned from the vulnerability of fixed GBAD systems observed in Iraq in 1991 and 2003 and in Libya in 2011.

This mobility, originally conceived during the Cold War, has been further optimized under operational pressure since the start of the full-scale invasion of Ukraine, where short- and medium-range systems (such as the SA-15 Gauntlet, SA-22, SA-11, SA-17, and SA-27) redeploy multiple times per

157. T. Nilsen, "Satellite Images Reveal Construction of Russian Radar to Track Stealthy F-35", *The Barents Observer*, June 27, 2022, available at: www.thebarentsobserver.com.

158. J. Bronk, N. Reynolds, and J. Watling, "The Russian Air War and Ukrainian Requirements for Air Defence", op. cit., p. 13.

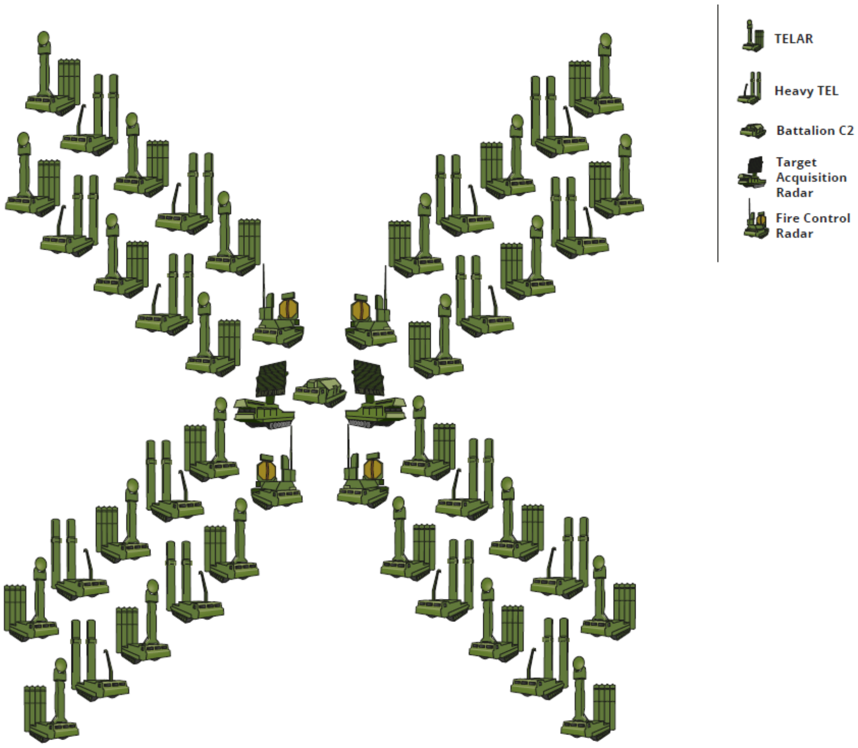
159. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit., p. 21.

160. C. Kopp, "KBP 2K22/2K22M/M1 Tunguska SA-19 Grison/96K6 Pantsir S1/SA-22 Greyhound SPAAGM", *Technical Report* APA-TR-2009-0703, Air Power Australia, April 2012, available at: www.ausairpower.net.

day.[161] Even long-range systems like the S-300 and S-400 routinely reposition faster than the planning and launch cycle of a cruise missile strike, which was the preferred method for neutralizing such systems in pre-2022 Western doctrine. As a result, the pre-planned suppression of medium- and short-range GBAD systems, which is central to offensive SEAD doctrine, has become increasingly difficult to execute using anti-radiation missiles. In Ukraine, the most effective SEAD results on both sides have been achieved through the use of theater ballistic missiles, such as ATACMS[162] and Iskander-M,[163] which offer the short flight times necessary to counter enemy mobility and enable successful dynamic targeting.

The resilience of modern Russian GBAD systems also relies on the redundancy of components within each battery, with multiple copies of each subsystem type included to mitigate the effects of attrition and technical failures.

**Figure 4: SA-23 battalion**




*Source: J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", Occasional Paper, RUSI, January 2020, p. 7.*

161. J. Bronk, "How Ground-based Air Defences Have Shaped the Air War over Ukraine", op. cit., pp. 137–167.

162. D. Axe, "Ukrainian ATACMS Rockets Are Blowing Up Russia's Best S-400 Air Defenses As Fast As The S-400s Can Deploy To Crimea", *Forbes*, June 12, 2024, available at: www.forbes.com.

163. B. Nikolov, "Kyiv 'Confirms Painful Strike' on Patriot Radar System by Iskander-M", *Bulgarian Military*, October 10, 2024, available at: https://bulgarianmilitary.com.

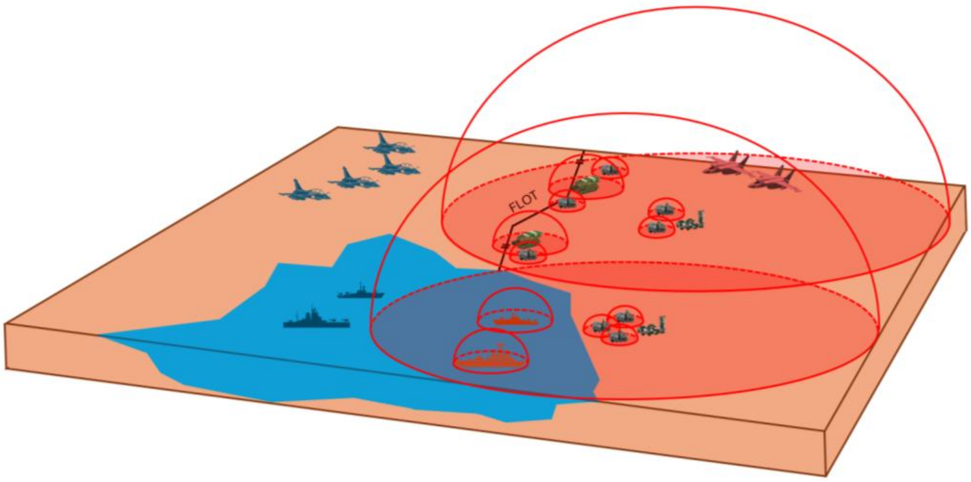
This resilience is further enhanced by interoperability across different iterations within the different families of GBAD systems. For example, the S-400's 30K6E administration system is capable of issuing engagement orders to all variants of the S-300, as well as to medium- and short-range systems from the Buk and Pantsir families.[164] Additionally, the S-400's 92N6E Grave Stone radar allows it to launch and guide all missile types within the S-300 family.

Last but not least, resilience also depends on quantity, particularly in the case of man-portable air defense systems (MANPADS). Because these simple, rapidly proliferating weapons have no electromagnetic signatures and are widely distributed among ground forces, it is virtually impossible to maintain absolute air dominance over the forward line of contact and the adversary's rear area below 15,000 feet in clear weather.

### Distribution and multiple layers

Beyond the inherent capabilities of Russian and Chinese GBAD systems, the primary threat to Western air superiority stems from their integration into a multi-layered IADS with distributed engagement capabilities.

**Figure 5: Schematic representation of the Russian IADS**




FLOT: forward line of own troops.

*Source: © Adrien Gorremans/Ifri, 2025.*

The Russian IADS, employed in Ukraine since spring 2022, is structured around a densely layered network that relies on multiple, mutually supporting and overlapping systems. The forward line is protected by infantry-carried MANPADS and short- and medium-range SAM, such as the Tor (SA-15) and Buk (SA-11, SA-17, and SA-27) systems, positioned just a few kilometers behind the line of contact. Long-range SAM batteries, including the S-300 (SA-20) and S-400 (SA-21), are deployed several dozen kilometers

164. C. Kopp, "Almaz-Antey 40R6/S-400 Triumf Self Propelled Air Defence System/SA-21", op. cit.

behind. These are themselves protected from air-launched weapons by short-range Pantsir (SA-22) systems.[165]

**Table 4: Traditional SEAD tactics and Russian counter-strategies**

| Target | SEAD/DEAD tactics and weapons | Russian counter-strategy |
|---|---|---|
| **Long-range SAMs (S-300, S-400, etc.)** | DEAD strike with standoff cruise missiles fired from all types of launch platforms | System mobility<br>Anti-missile capability<br>Close-in defense (C-RAM) |
| **Medium- or short-range system with known approximate position** | Preventive suppression through continuous engagement by anti-radiation missiles on coordinates (Pre-Briefed or PET shot) by dedicated SEAD aircraft | Engagement before reaching HARM range by long-range SAMs<br>System mobility |
| **Medium- or short-range system whose approximate position is suspected** | Reactive suppression through continuous engagement by anti-radiation missiles after localization by electronic intelligence (ELINT): Target of Opportunity (TOO) mode by dedicated SEAD aircraft | Engagement before reaching HARM range by long-range SAMs<br>System mobility<br>Distributed fires<br>Emission control (EMCON) |
| **Medium- and short-range systems that switch on their radar at the last minute to engage stand-in penetrating aircraft** | Reactive suppression through immediate Self-Protect anti-radiation missiles shot by SEAD escort aircraft | Engagement before reaching HARM range by long-range SAMs<br>System mobility<br>Distributed fires<br>EMCON |

*Sources: J. Bronk, "How Ground-based Air Defences Have Shaped the Air War over Ukraine", and the author's operational experience.*

Networking sensors and firing units while geographically dispersing system components theoretically allows for distributed engagements using firing units supported by remote fire-control radars.[166] As a result, an enemy

165. Research interviews with French and Ukrainian senior officers.
166. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit.

aircraft entering the engagement envelope of any IADS component can be targeted even if the firing system's own fire-control radar is inactive. Crucially, this networked architecture also allows the IADS to be cued by early warning data from long-range surveillance and OTH radars, as well as from A-50U Mainstay airborne early warning and control (AEW&C) aircraft and MiG-31BM fighters conducting defensive patrols above long-range SAM positions. These latter two assets play a critical role in low-altitude detection,[167] while also covering threat axes that are less protected by GBAD systems.

We will conclude this assessment of the GBAD threat posed by the West's potential adversaries with one observation: Any weapons system or combat aircraft attempting to penetrate such an IADS will have to contend with multiple layers of GBAD systems simultaneously, as well as a limited number of adversary air defense aircraft. Crucially, it will no longer be feasible to treat each GBAD system or site as an isolated target, which fundamentally challenges the viability of traditional SEAD tactics.

The IADS described above should, however, be viewed as a nominal threat—an idealized model of networked operations against which the West must prepare for future air warfare. In reality, numerous technical, human, and procedural friction points undermine its actual level of integration.[168] The air war over Ukraine has demonstrated that although the Russian IADS remains among the most capable in the world, it operates far below its theoretical potential, as made clear by incidents of fratricide[169] and by the successful penetration of Russian airspace by cruise missiles launched by Ukraine.[170]

## Emerging threats and technological breakthroughs

Beyond these traditional air superiority capabilities, the West's potential adversaries, led by Russia and China, are rapidly developing military capabilities designed as counter-strategies to circumvent or erode Western air power. Four emerging threats are particularly concerning in this context: electronic warfare, deep precision strike, drone warfare, and the use of very high altitude (VHA).

167. J. Bronk, "Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook", op. cit., p. 27.
168. J. Bronk, "How Ground-based Air Defences Have Shaped the Air War over Ukraine", op. cit., pp. 137–167.
169. K. Hodunova, "UK Military Intelligence: Ukrainian Strikes Overload Russian Air Defense, Causing 'Friendly Fire'", *The Kyiv Independent*, April 7, 2024, available at: https://kyivindependent.com.
170. T. Newdick, "Black Sea Fleet Headquarters Takes Direct Hit from Cruise Missile", *The War Zone*, September 22, 2023, available at: www.twz.com.

## *Electronic warfare: Another form of anti-access*

Advancements in electronics and computing, along with their miniaturization and global dissemination during the 1990s and 2000s, have made complex but widespread civilian technologies available for military applications. One key consequence of this trend is the proliferation and increasing diversity of electronic warfare systems. The cost of accessing these technologies is minimal compared to the level of disruption they can impose on Western air forces, because they are capable of targeting several of their critical operational functions.

The first practical application of electronic warfare in air operations is the interception of an adversary's electromagnetic emissions to detect and identify aircraft, a capability known as signals intelligence (SIGINT). This function partially offsets the advantages of radar stealth. Russia deploys a range of ground-based systems dedicated to intercepting airborne radar and communication signals, such as the Moskva-1 1L267.[171]

After having initially not installed self-protection radar jammers on its early fourth-generation aircraft in the 1980s, Russia has since developed and integrated digital radio frequency memory (DRFM) technology. Most Flanker variants currently in service with the VKS are equipped with self-protection jamming systems, such as the L-175V Khibiny.[172] Here, as in the field of radar, China has likely surpassed Russia, as evidenced by the operational deployment of the J-16D, a platform dedicated to electronic attack.[173] Russia has also invested in ground-based radar jamming systems, including the Krasukha-2 and Krasukha-4, designed to electronically disrupt NATO's critical capabilities—particularly the E-3 AWACS aircraft, which are essential for achieving air superiority. [174]

In addition to radar jamming, Russia and North Korea[175] have understood the heavy reliance of Western air forces on precision-guided munitions and have developed a variety of GPS jamming systems, including

171. M. Creery, "The Russian Edge in Electronic Warfare", *Georgetown Security Studies Review*, Georgetown University Center for Security Studies, June 26, 2019, available at: https://georgetownsecuritystudiesreview.org.

172. J. Trevithick, "Ukraine Just Captured One Of Russia's Most Capable Aerial Electronic Warfare Pods", *The War Zone*, September 12, 2022, available at: www.twz.com; G. Plopsky and J. Bronk, "Russian SEAD Efforts During the Air War in Ukraine", in D. Henriksen and J. Bronk (eds.), *The Air War in Ukraine: The First Year of Conflict*, pp. 109–110.

173. "China's J-16D Electronic Warfare Aircraft Reveals Jamming Pods, Missiles at Airshow China 2021", *Global Times*, September 28, 2021, available at: www.globaltimes.cn.

174. "Krasukha Electronic Warfare (EW) System, Russia", *Army Technology*, January 5, 2024, available at: www.army-technology.com.

175. "N. Korea Continues GPS Jamming Attack for 4th Day", *The Korea Times*, June 1, 2024, available at: www.koreatimes.co.kr.

the Pole-21E[176] and R-330Zh Zhitel.[177] They have also fielded defensive jamming systems designed to neutralize the fuzing mechanisms of Western munitions in order to prevent detonation upon impact, such as the SPR-2M Rtut-BM.[178]

Although these electronic warfare systems, unlike their Western counterparts, are generally non-discriminatory and often degrade Russian capabilities as much as those of the adversary,[179] the battle for control of the air can no longer be envisioned outside of a contested electromagnetic environment. From this perspective, the primary operational consequences of these jamming capabilities are:

- uncertainty about the resilience of global navigation satellite systems (GNSS);
- uncertainty about the reliability of precision-guided munitions, both in terms of accuracy and military effects;
- and a probable deterioration in the performance of onboard sensors, inducing significantly reduced detection and engagement ranges compared with a jamming-free environment.

These various capabilities do not fundamentally shift the technological balance, which continues to favor Europe and the United States in terms of control over the electromagnetic spectrum. However, their large-scale deployment relative to Europe's more limited approach, combined with the emergence of AI in adaptive jamming programming, could soon alter the situation. Russia, in particular, is testing and refining its electronic warfare systems in Ukraine and Syria, something the West has done only to a limited extent.

### *Deep precision strike capabilities*

One of the foundations of Western air superiority has been the ability to operate from a secure rear area, free from adversary threats, where air bases, fuel and ammunition depots, and the complex logistical infrastructure essential to sustaining air operations could function without disruption. This has been the operational norm for Western air forces since the end of the Second World War because their potential adversaries—with the exception of the Soviet Union during the Cold War—were unable to conduct deep precision strikes. To turn Air Marshal Arthur "Bomber" Harris's famous expression on its head, the West entered the twenty-first century under the

176. "Pole-21E Russian RF Jammer", *ODIN*, *Worldwide Equipment Guide*, TRADOC, US Army, available at: https://odin.tradoc.army.mil.
177. T. Withington, "Jamming JDAM: The Threat to US Munitions from Russian Electronic Warfare", RUSI, June 6, 2023, available at: www.rusi.org.
178. M. Dura, "Electronic Warfare: Russian Response to the NATO's Advantage?", *Defence24*, May 5, 2017, available at: https://defence24.com.
179. G. Plopsky and J. Bronk, "Russian SEAD Efforts During the Air War in Ukraine", op. cit., pp. 106–136.

childish delusion that it could bomb everybody else, and nobody was going to bomb them back.[180]

Several potential adversaries do, however, possess long-range precision strike capabilities that allow them to threaten air bases and infrastructure contributing to air control by circumventing the traditional strengths of Western air power from either above or below. These adversaries have access to three main categories of long-range precision strike systems: ballistic and hypersonic missiles, cruise missiles, and long-range saturation weapons.[181]

## Ballistic proliferation

Until the 1990s, ballistic missiles were the exclusive preserve of a small number of state actors. In the twenty-first century, however, they have become increasingly widespread and diversified; this technology is now proliferating among the West's potential adversaries. Ballistic missiles play a critical role in asymmetric air strategies, offering a cost-effective way to bypass air power from above to strike the foundations of the adversary's air power. Only a very limited subset of weapons systems can neutralize this ballistic threat, and even then only partially. At the theater level, there remains no systematic or fully effective response to a saturating ballistic missile salvo, as demonstrated by the successes of Israeli, Iranian, Russian, and Ukrainian ballistic strikes since February 24, 2022.

Iran and its various regional proxies possess a comprehensive arsenal of 15 types of short-range ballistic missiles (SRBMs) and medium-range ballistic missiles (MRBMs),[182] including some equipped with maneuverable reentry vehicles (MaRVs).[183] These were the only weapons that successfully penetrated Israeli air defenses during the attack of April 13, 2024.[184] Russia fields 12 brigades of Iskander-M SRBMs[185] and has modified at least 10 MiG-31Ks[186] to carry Kh-47M2 Kinzhal air-launched ballistic missiles (ALBMs). China, for its part, has made its ballistic missile program a central pillar of its interdiction strategy targeting US bases throughout the first and second island chains, extending as far as Guam. The Chinese arsenal includes a full spectrum of

180. "The Nazis entered this war under the rather childish delusion that they were going to bomb everybody else and nobody was going to bomb them". Video message from Air Marshal Arthur Travers Harris, IWM film RMY 112, June 3, 1942.

181. H. Fayet and L. Péria-Peigné, "La frappe dans la profondeur: Un nouvel outil pour la compétition stratégique?", *Focus stratégique*, No. 121, Ifri, November 2024, available at: www.ifri.org.

182. *Military Balance 2024*, op. cit., p. 354.

183. F. Hinz, "Removing the Hype from Iran's 'Hypersonic' Conqueror", *Military Balance Blog*, IISS, July 14, 2023, available at: www.iiss.org.

184. M. Raddatz, "Minor Damage Reported at 2 Israeli Air Bases", *ABC News*, April 14, 2024, available at: https://abcnews.go.com.

185. *Military Balance 2024*, op. cit., p. 192.

186. "Ten MIG-31 Fighter Jets Fitted with Kinzhal Air-launched Missiles on Test Combat Duty", *TASS*, May 5, 2018, available at: https://tass.com.

SRBMs and MRBMs, at least one of which (the DF-17)[187] is equipped with a hypersonic glide vehicle.

In the event of a large-scale conflict, Western air bases could be required to operate under the threat of adversary ballistic missile fire. Preemptively neutralizing these missile systems would be a priority objective, but their dispersion and camouflage would make this goal hard to achieve, as evidenced by American attempts to locate and destroy Iraqi Scud launchers in 1991.[188]

### Cruise missiles

Until the late 1990s, cruise missile technology, like ballistic missile technology, was mastered by only a few countries: the United States, France, and Russia.[189] Today, it is widely proliferated among several middle powers. Launched from land platforms, naval vessels, or combat aircraft, cruise missiles pose a particularly complex threat because of their very low-altitude flight profiles, which limit and delay radar detection. They typically have ranges of several hundred nautical miles and are a preferred option for standoff strikes aimed at degrading enemy air assets.[190] Their extended range also allows for flight paths that can bypass adversary air defenses and preserve ambiguity as to the intended target.

Russia has three families of conventional cruise missiles. These are centered around the air-launched Kh-59M[191] (AS-18 Kazoo) and Kh-55 variants[192] (AS-15 Kent, AS-22 Kluge, and AS-23 Kodiak) and the sea-launched 3M54-1 Kalibr[193] (SS-N-27 Sizzler). However, their employment until 2025 has been constrained by heavy reliance on US-origin components and limited stockpiles since the start of the invasion of Ukraine, although the production has steadily increased in 2024.[194] China appears to place less emphasis on cruise missiles outside of the anti-ship domain, having prioritized its ballistic missile program. Its land-attack cruise missile capability appears limited to a few dozen CJ-100/DF-100 systems.[195] Iran has

187. T. Newdick, "This Is Our Best Look Yet At China's Air-Launched 'Carrier Killer' Missile", *The War Zone*, April 19, 2022, available at: www.twz.com.

188. S. M. Powell, "Scud War, Round Two", *Air & Space Forces Magazine*, April 1, 1992, available at: www.airandspaceforces.com.

189. D. M. Gormley, *Missile Contagion: Cruise Missile Proliferation and the Threat to International Security*, Westport: Praeger Publishing, 2008.

190. "Gunfire, Explosions Heard in Tripoli", *CNN*, March 19, 2011, available at: https://cnnpressroom.com.

191. C. Kopp, "Soviet/Russian Tactical Air to Surface Missiles", *Technical Report* APA-TR-2009-0804, Air Power Australia, April 2012, available at: www.ausairpower.net.

192. C. Kopp, "Soviet/Russian Cruise Missiles", *Technical Report* APA-TR-2009-0805, Air Power Australia, April 2012, available at: www.ausairpower.net.

193. Ibid.

194. J. Byrne et al., "Silicon Lifeline: Western Electronics at the Heart of Russia's War Machine", *Special Resources*, RUSI, August 2022, available at: https://rusi.org; "Ukrainian Intelligence Reveals How Russia Increased Its Missile Stockpile Over the Year", *Defense Express*, December 28, 2024, available at: https://en.defence-ua.com.

195. "First PLA Rocket Force CJ-100 Unit Likely Identified", China Aerospace Studies Institute, November 2020, available at: www.airuniversity.af.edu.

developed several ground-launched variants of the Kh-55, including the Soumar and its successor, the Paveh,[196] which was used in the strike of April 13, 2024. Israel, India, and Turkey also possess conventionally armed cruise missiles and could potentially export them. By contrast, Pakistan[197] and North Korea[198] have focused their cruise missile development efforts on nuclear delivery platforms.

As with ballistic missiles, potential adversaries of the West now possess low-altitude, long-range strike capabilities that allow them to threaten the Western rear area, thereby holding the foundations of Western air superiority at risk.

### Long-range saturation weapons

Finally, the most significant strategic shift in the domain of long-range precision strike lies in the emergence of low-cost weapons that blur the lines between cruise missiles, drones, and loitering munitions, a prime example of which is the Shahed-131/136 series developed by Iran and exported to Russia following the invasion of Ukraine. These platforms, known as one-way attack (OWA) munitions or effectors, are defined by two key characteristics: their simplicity and their extended range, enabling long-range precision strikes at a remarkably low unit cost, estimated to be roughly twenty times cheaper than a cruise missile.[199] While their individual effectiveness in penetrating defenses and delivering military effects is significantly inferior to that of cruise missiles, mass producing them makes it possible to saturate enemy air defenses. Whether or not they are reprogrammable or controllable in flight, they represent a means of bypassing traditional IADS from the bottom up, enabling poorer actors to challenge high-end systems as part of a salvo competition.[200] Their use has the potential to cripple an adversary while depleting its surface-to-air and air-to-air missile reserves.

In addition to Russia's extensive use of the Shahed-131/136 and their Russian variant, the Geran-2—over 4,200 of which had been launched in Ukraine as of February 2024—this category of munition has also been employed by Ukraine against Russia.[201] The Houthis have made regular use

196. "Soumar (Hoveyzeh, Abu Mahdi)", *Missile Threat*, *CSIS Missile Defense Project*, CSIS, April 23, 2024, available at: https://missilethreat.csis.org.
197. H. M. Kristensen, M. Korda, and E. Johns, "Pakistan Nuclear Weapons, 2023", *Bulletin of the Atomic Scientists*, September 11, 2023, available at: https://thebulletin.org.
198. V. H. Van Diepen and 38 North, "Initial Analysis of North Korea's 'New Type Long-Range Cruise Missile'", Stimson Center, September 15, 2021, available at: www.38north.org.
199. A. Terajima, "Explainer: Iran's Cheap, Effective Shahed Drones and How Russia Uses Them in Ukraine", *The Kyiv Independent*, April 17, 2024, available at: https://kyivindependent.com.
200. M. Gunzinger and B. Clark, "Winning the Salvo Competition: Rebalancing America's Air And Missile Defenses", CSBA, May 20, 2016, available at: https://csbaonline.org.
201. A. Terajima, "Explainer: Iran's Cheap, Effective Shahed Drones and How Russia Uses Them in Ukraine"; J. Bronk, "Damaged Su-57 Emphasises the Vulnerability of Russian Airbases Near Ukraine", *Commentary*, RUSI, June 10, 2024, available at: www.rusi.org.

of them against Saudi Arabia and in the Red Sea;[202] they have even managed to strike Israel, though with limited operational effectiveness.[203] Given the simplicity and effectiveness of this concept, it is highly likely that a growing number of state and non-state actors will adopt this type of system in the coming years.

Access to all three categories of weapons—ballistic missiles, cruise missiles, and low-cost, long-range weapons—by geopolitical actors increasingly uninhibited in their use of force marks a significant shift in the threat landscape for the infrastructure underpinning Western air power. The most concerning scenario is the combined use of these three strike systems to saturate defenses both technically and cognitively. Russia regularly conducts this type of complex attack, albeit on a limited scale because of constraints in industrial production capacity, stockpile depletion, and shortcomings in targeting methodology.[204] Iran demonstrated its ability to conduct such coordinated strikes on April 13, 2024. While the operational impact of that symbolic strike was limited—part of a calibrated escalation management approach—it should not be underestimated.[205] In the event of a broader escalation in the Middle East or the Asia-Pacific, there is a significant risk that Western air bases will be effectively targeted by larger salvos.[206]

202. P. Wintour, "Houthi Forces Step up Red Sea Attacks as US and Denmark Shoot Down Drones", *The Guardian*, March 9, 2024, available at: www.theguardian.com.

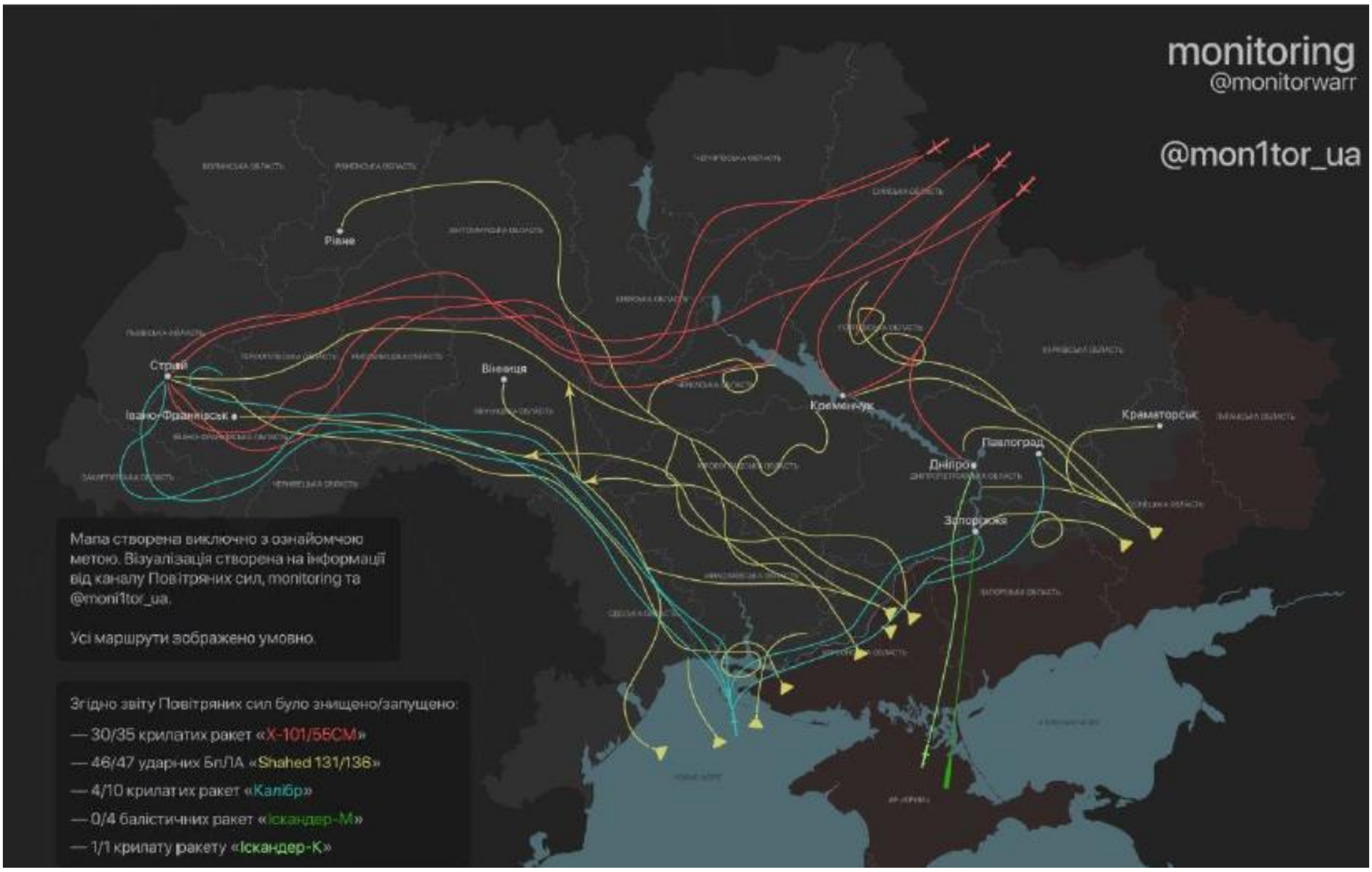
203. "Major Saudi Arabia Oil Facilities Hit by Houthi Drone Strikes", *The Guardian*, September 14, 2019, available at: www.theguardian.com; "Evolution of UAVs Employed by Houthi Forces in Yemen", *Dispatch from the Field*, Conflict Armament Research, February 2020, available at: www.conflictarm.com; E. Fabian, "Explosive Drone from Yemen Hits Tel Aviv Apartment, Killing One Man, Wounding Others", *The Times of Israel*, July 19, 2024, available at: www.timesofisrael.com.

204. J. Watling, "Long-range Precision Fires in the Russo-Ukrainian War", in D. Henriksen and J. Bronk (eds.), *The Air War in Ukraine: The First Year of Conflict*, op. cit., pp. 66–85.

205. "Iran's Retaliatory Strikes Have Begun (Updated)", *The War Zone*, April 14, 2024, available at: www.twz.com.

206. J. M. Dahm, "Fighting the Air Base: Ensuring Decisive Combat Sortie Generation Under Enemy Fire", *Policy Paper*, Vol. 51, Mitchell Institute, July 11, 2024, available at: https://mitchellaerospacepower.org.

**Figure 6: Complex air strike conducted by the Russian Federation against Ukraine on June 1, 2024**




*Source: Telegram channel t.me/monitorwarr.*

## *The proliferation of drones*

Beyond long-range precision strike capabilities, the rapid evolution of drone technologies since the 2010s has created new opportunities for asymmetric attacks, both against infrastructure critical to air operations (such as air bases, radar installations, and C2 centers) and against GBAD systems. Three particularly serious threats are posed by drone-related capabilities in the contest for control of the air.

The first threat lies in the use of decoy drones to saturate air defenses, operating alongside crewed aircraft or missiles to help penetrate an adversary's IADS. The objective is to force the defender to allocate fire-control radar attention to these decoys and expend interceptors on radar returns that closely mimic the behavior and signature of actual combat aircraft, thus depleting missile inventories and overwhelming the defender's situational awareness (SA), thereby creating openings for the "real" strike platforms to enter the IADS engagement zone.

While diversionary raids have been widely employed since the Second World War, the use of drone-based decoys was introduced in the late 1980s by the United States Air Force, the United States Navy, and the Israeli Air Force.[207] The USAF's current OCA doctrine makes extensive use of the ADM-160 Miniature Air-Launched Decoy (MALD), which has also been employed by the Ukrainian Air Force to support SCALP/Storm Shadow cruise missile strikes.[208] Few other countries appeared to explore this capability until the late 2010s. To date, aside from Russia's aforementioned use of Shahed-136s in Ukraine, the most concerning development in this domain is China's large-scale conversion of its aging second- and third-generation fighter fleet into decoy platforms.[209] Specifically, China is repurposing its extensive inventory of J-6 Farmer and J-7 Fishcan aircraft—Chinese variants of the Soviet MiG-19 Farmer and MiG-21 Fishbed—to act as expendable decoys in place of more advanced fourth- and fifth-generation fighters.

The second threat lies in the ability to inflict targeted damage on infrastructure, aircraft, and GBAD systems through special forces teams infiltrating the adversary's rear area. This method is not new: It dates back to 1942 with operations conducted by the British SAS.[210] It remains constrained by operational limitations, including the small number of available teams and the challenges of inserting them into enemy territory. However, the use of militarized civilian drones significantly amplifies their destructive potential and enhances the survivability of operators deployed deep in hostile territory.[211]

The third threat lies in the proliferation of asymmetric SEAD capabilities for states lacking access to traditional SEAD systems. A combination of remotely operated munitions and armed MALE drones can significantly degrade an adversary's GBAD systems. This strategy would necessarily be incremental: The range of remotely operated munitions is typically limited to only a few dozen kilometers beyond the forward line of contact, while MALE drones remain vulnerable to SAMs. However, the approach becomes cost-effective when drones are treated as expendable assets: They represent a far smaller investment for the attacker than the cost of defensive interceptors for the defender. For Ukraine, employing several dozen MALE drones against Russia's IADS, which comprises over a thousand interlinked surface-to-air systems, would have minimal operational impact.

207. "ADM-141A Tactical Air-Launched Decoy (TALD)", Federation of American Scientists, April 23, 2000, available at: https://man.fas.org.

208. T. Newdick, "ADM-160 Miniature Air Launched Decoy Spotted On Ukrainian MiG-29", *The War Zone*, May 21, 2024, available at: www.twz.com.

209. D. Rice, "Hardened Shelters and UCAVs: Understanding the Chinese Threat Facing Taiwan", *The Mitchell Forum*, No. 47, Mitchell Institute, November 2022, available at: https://mitchellaerospacepower.org.

210. G. Mortimer, *Stirling's Desert Triumph: The SAS Egyptian Airfield Raids 1942*, Oxford: Osprey Publishing, 2012.

211. "Russian Factory Fixing Advanced A-50 Spy Plane Damaged in Strike: Reports", *Newsweek*, March 9, 2024, available at: www.newsweek.com.

By contrast, Azerbaijan's approach in 2020, which consisted of the use of several dozen drones and remotely operated munitions to target a few dozen scattered Armenian GBAD systems, which lacked coordination, proved strikingly effective.[212]

## *Exploiting very high altitudes*

Finally, the very high altitude (VHA) domain—above 20 km (66,000 feet)—is beginning to be actively explored, particularly by China. Since the 1960s, the United States and Russia have operated reconnaissance aircraft capable of reaching the VHA domain, such as the SR-71 Blackbird and the M-55 Mystic. However, these platforms operated at the lower end of the VHA spectrum, at altitudes not exceeding 85,000 feet. Such altitudes are now within the engagement envelope of most modern long-range SAMs.

By contrast, the early 2020s have seen the introduction or development of several new types of VHA platforms, beyond ballistic and hypersonic missiles. These include slow, persistent systems, such as balloons and solar-powered aircraft, that are primarily used for intelligence gathering or as communication relays. Often called "pseudo-satellites",[213] these platforms pose significant challenges to existing air defense systems, including:

- detection problems, because they operate above the search volume of most surveillance radars;
- identification and attribution problems, since visual recognition by existing platforms becomes extremely difficult above 50,000 to 60,000 feet;
- and engagement problems, because these slow, low-metal platforms have a low RCS and low relative speed, making them difficult targets for Doppler fire-control radars.

The Chinese balloon flight over US territory in February 2023—reportedly accidental in origin[214]—highlights the potential of VHA platforms to introduce new forms of competition below the threshold of open conflict. It also suggests the emergence of a kind of techno-guerrilla warfare for actors seeking to offset limited access to space-based capabilities.[215]

A wide array of emerging threats now challenges the ability of Western air forces to achieve and maintain air superiority. While Russia's VKS appear unable to project credible air power beyond the immediate front line, China

212. M. Goya, "Les enseignements opérationnels de la guerre du Haut-Karabakh", *La Voie de l'Epée*, December 1, 2020, available at: https://lavoiedelepee.blogspot.com.

213. M. Alligier and P. Bouhet, "La très haute altitude: Un champ de réflexion de l'armée de l'Air et de l'Espace", *DSI hors-série*, No. 90, June–July 2023, available at: www.areion24.news.

214. K. Bo Lillis and N. Bertrand, "China Appears to Have Suspended Spy Balloon Program After February Shootdown, US Intel Believes", *CNN*, September 15, 2023, available at: https://edition.cnn.com.

215. J. Henrotin, "Techno-guérilla: Le pire des deux mondes", *Areion24news*, February 27, 2022, available at: www.areion24.news.

is developing substantial capabilities tailored to the specific geography of its strategic environment. More critically, new options for striking the rear area, which NATO forces have long considered a safe zone, pose a serious risk to the operational foundations of Western air power. When combined with the effectiveness of modern IADS, these developments form a set of circumvention and anti-access strategies that, while concerning, should not lead to fatalism. Instead, they point to the need to redefine air superiority and its objectives. With targeted investments in capabilities, technologies, and doctrinal innovation, it remains possible to overcome these challenges and secure a relevant and operationally useful control of the air.

# *Tactics* – Achieving air superiority today

In light of the threats outlined above, this section offers a dual perspective on the concept of air superiority for the period 2025–2035. First, it presents a set of considerations related to air combat, to be assessed in parallel with the evolution of traditional aerial and SAM threats mentioned above. Second, it outlines two primary categories of responses to the dilemmas posed by strategies aimed at bypassing Western air power. Gaining air superiority will require a paradigm shift in terms of both capabilities and tactics, from a traditionally Western platform-centric mindset to a saturation-focused mindset. In parallel, several purely technological advancements will be necessary to preserve Western superiority in the air domain.

## Future air combat

The contest for air superiority hinges on several key technical and operational factors, including attrition rates, radar stealth, and the impossibility of fully controlling low-altitude airspace. Future outcomes will be shaped by the evolution of air-to-air combat, which will be driven not only by advances in weapon range and stealth technologies, but also by SEAD capabilities adapted to the latest threats.

### *Technical and operational factors*

Absent any major technological breakthroughs, the battle for air superiority over the next decade will be shaped mainly by three considerations.

- The first is the return of attrition, driven by the widespread proliferation of increasingly effective weapons systems across all domains. The ability of air forces to endure both human and material attrition is a growing concern, especially given the lengthy timelines required to replenish munitions and aircraft inventories (often several years) compared with the relatively short windows during which decisive air supremacy can be achieved before operations devolve into prolonged attritional warfare (typically a matter of weeks).
- The second is radar stealth, which will remain a decisive factor on the modern air battlefield. Since the 1990s, it has fundamentally altered the tactics, techniques, and procedures of both air-to-air combat and SEAD operations. Whereas fourth-generation platforms typically use range-based tactics, fifth-generation systems operate under angular

constraints that redefine the geometry of the engagements. Stealth technology indeed has physical limitations and does not prevent detection by electro-optical sensors in clear weather.[216] It can be partially countered by AESA radar systems when not supported by radar jamming.[217] Maintaining stealth capabilities in operational condition remains extremely resource-intensive,[218] requiring significant technical and human investment that is often incompatible with the logistical constraints and chaotic environment of a modern battlefield.[219] But despite these constraints, stealth continues to be a core operational feature in relation to which modern air superiority systems are structured, and it will remain a game-changing tactical capability for the foreseeable future.

- Finally, at lower altitudes—between ground level and 10,000 to 15,000 feet—air superiority will become increasingly difficult to establish, owing to the proliferation of MANPADS and all manner of unmanned platforms. Systematic preemptive destruction of these systems before launch is nearly impossible. In this so-called "air littoral", achieving control of the air will rely on an integrated approach that combines GBAD systems with swarms of combat drones, and with an emphasis on denial rather than outright conquest.[220]

### *Air-to-air combat*

The air warfare platforms that will dominate the next two decades are either already in service or currently in testing,[221] with the exception of the US Next Generation Air Dominance (NGAD) program, which is already facing budgetary challenges.[222] As a result, no major breakthroughs in platform design are expected before 2035. By contrast, significant advances are being made in the range and lethality of air-to-air weaponry, driven by the development of three emerging families of air-to-air missiles:

- missiles similar in size to previous-generation medium-range air-to-air weapons, but featuring dual-pulse propulsion technology—such as the MICA NG, the AIM-120D, the PL-15, and the K-77M—with engagement ranges in the vicinity of 100 NM;

216. Research interviews with aeronautical engineers specializing in electro-optical sensors.
217. Research interviews with senior officers of the French Air and Space Force.
218. N. McCarthy, "The Mammoth Cost of Operating America's Combat Aircraft", *Forbes*, November 26, 2020, available at: www.forbes.com.
219. Research interview with a retired general officer of the French Air and Space Force.
220. M. K. Bremer and K. A. Grieco, "Contesting the Air Littoral", in *Aether*, Vol. 3, No. 3, Autumn 2024, available at: www.airuniversity.af.edu.
221. Lecture given under the Chatham House rule by an anglophone air power specialist.
222. S. Losey, "Next-gen Fighter Not Dead, But Needs Cheaper Redesign, Kendall Says", *Air Warfare*, *Defense News*, July 1, 2024, available at: www.defensenews.com.

- very large air-to-air missiles, such as the PL-17 and AIM-174, with ranges of around 200 NM, but too large to be carried internally by fifth-generation aircraft;
- and ramjet-powered air-to-air missiles functioning as genuine anti-aircraft cruise missiles, such as the Meteor and the upcoming Chinese PL-21.

In this evolving technological environment, the current Western paradigm, built on radar stealth, advanced air-to-air missile performance, connectivity, and electronic warfare,[223] remains highly relevant. The optimal high-low mix, or force structure, will consist of a limited number of fifth-generation LO or VLO fighters, manned or unmanned, providing superior detection and engagement capabilities in highly contested environments, supported by a larger fleet of fourth-generation fighters to deliver the firepower, mass, persistence, and concentration of effort required to saturate and overwhelm adversary air combat capabilities.[224] This force model remains critically dependent on a suite of standoff support systems, many of which can be mounted on satellites or drones, including AEW, ELINT, offensive jamming, air-to-air refueling, and more.

The continued spread of radar stealth is likely to reshape the nature of air-to-air combat by shifting it away from the traditional emphasis on the energy performance of fourth-generation fighters toward a contest centered on electromagnetic signature management. This evolution could turn air combat into a fast-paced analogue of submarine warfare, where the primary objective is to detect and engage the adversary before being detected. Passive detection systems will likely become increasingly important for manned aircraft, while the battlespace is expected to be saturated with sensors and weapons mounted on cheap, low-performance drone platforms, such as the American XQ-58 Valkyrie.[225] Engagements between fifth-generation fighters may increasingly resemble meeting engagements: Bursts of air superiority would enable temporary access to the adversary's operative and strategic targets,[226] with fighters occasionally and unpredictably engaging at short range.

Friction and the fog of war, exacerbated by the omnipresence of stealth and electronic warfare, will likely reduce both detection and engagement ranges, as well as the probability of kill (Pk) of air-to-air weapons. As a result, engagements are increasingly expected to become decisive within visual range. In this environment, air forces that have maintained proficiency in dogfight, preserved air-to-air gun capabilities, and invested in helmet-

223. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit., p. 27.
224. Research interviews with senior officers of the French Air and Space Force and anglophone air power specialists.
225. J. Trevithick, "XQ-58 Valkyrie Drone Family Has Grown to Five Variants", *The War Zone*, March 21, 2024, available at: [www.twz.com](www.twz.com).
226. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit., p. 19.

mounted sights paired with electro-optically guided missile systems will hold a distinct advantage.

Finally, the most significant development in air combat is likely the omnipresent GBAD threat, which can no longer be considered a separate domain. This necessitates the development of tactics that integrate air-to-air and SEAD operations simultaneously.

## SEAD

The state of mutual air denial that has defined the Russo-Ukrainian war since February 2022 has led some analysts and senior officials to argue that, given the density of the Russian and Chinese IADS, achieving offensive air superiority has become nearly impossible. They have instead advocated air strategies that prioritize a defensive posture.[227]

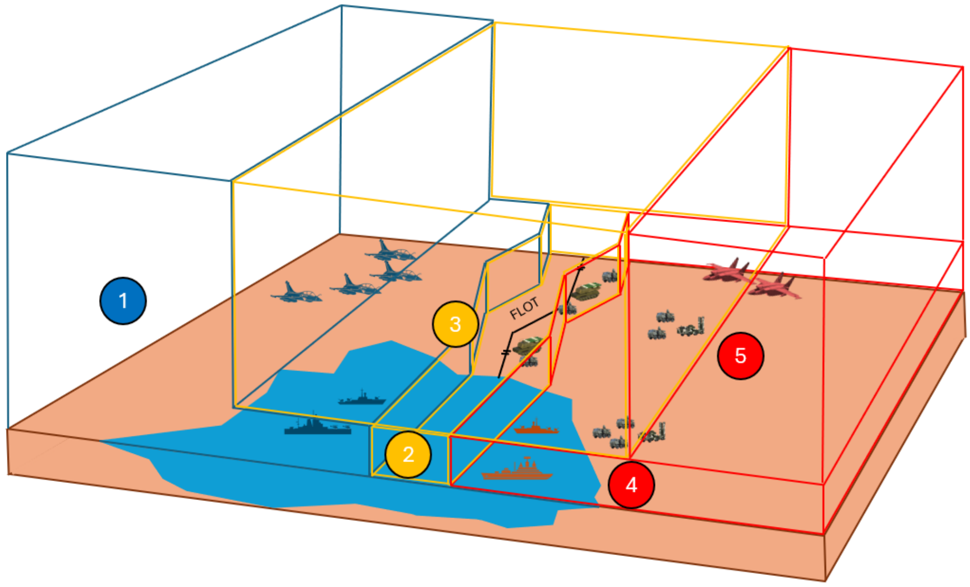
Indeed, there is at least one exclusion zone where achieving sustained air supremacy now appears impossible: low altitude (below 15,000 feet) over enemy forces and territory, commonly referred to in the American literature as the "air littoral".[228] As a result, the definition of air control over enemy territory can be limited to the ability to operate at medium and high altitudes without interference.

With respect to medium and high altitudes, however, this pessimism should be tempered by the fact that in Ukraine, both air forces suffer from significant weaknesses that result in an uneven fight against the opposing IADS.

- The VKS were unable to carry out a successful SEAD campaign due to doctrinal shortcomings,[229] inadequate crew training, and operational subordination to the Russian Army.[230]
- The Ukrainian Air Force, whose command structure remains influenced by the Soviet model, faces one of the most capable IADS in the world with a relatively small aviation force equipped with outdated fighters from the 1980s. Despite the limited integration of the AGM-88 HARM anti-radiation missile, Ukrainian pilots have been unable to significantly degrade the Russian IADS.

227. Army General P. Schill, post on LinkedIn quoted by L. Lagneau, "Pour le chef d'état-major de l'armée de Terre, l'artillerie est maintenant la 'reine des batailles'", *Zone militaire*, January 21, 2024, available at: www.opex360.com.
228. M. K. Bremer and K. A. Grieco, "Contesting the Air Littoral", op. cit.
229. G. Plopsky and J. Bronk, "Russian SEAD Efforts During the Air War in Ukraine", op. cit., pp. 106–136.
230. Lt. Gen. D. A. Deptula and Dr. C. J. Bowie, "The Significance of Air Superiority: The Ukraine-Russia War", *Policy Paper*, Vol. 50, Mitchell Institute, July 2024, pp. 5–7, available at: https://mitchellaerospacepower.org.

### Figure 7: Air superiority zones




| | |
|---|---|
| 1 | Friendly rear area – Superiority / supremacy / dominance ensured by the friendly IADS (fighter aircraft, SAMs, AAA) |
| 2 | Low altitude contact zone – Mutual denial by GBAD (AAA, MANPADS, short and medium-range SAMs); temporary air superiority can be acheived through saturation, air supremacy is not achievable |
| 3 | High and medium altitude contact zone – Mutual denial by DCA (fighter aircraft, medium and long-range SAMs), superiority / supremacy / dominance achievable through OCA, especially through SEAD |
| 4 | Enemy rear area, low altitude - Denial by DCA (fighter aircraft, AAA, MANPADS, SAMs of all ranges), temporary air superiority possible through saturation ou terrain-following; air supremacy is not achievable |
| 5 | Enemy rear area, medium and high altitude – Denial by DCA (fighter aircraft, medium and long-range SAMs), superiority / supremacy achievable through OCA, especially through SEAD |

*Source: © Adrien Gorremans/Ifri, 2025.*

On the other hand, given a comparable level of technology, combat aircraft hold a major conceptual advantage over a GBAD-based IADS: They can seize the initiative, which allows them to leverage the core strengths of air power—flexibility, speed, and concentration of firepower. Penetrating and neutralizing an IADS, no matter how complex, remains achievable for a coalition of Western combat aircraft, provided there is sustained technological and doctrinal investment in the critical domains of SEAD and targeting. For example, the Israeli Air Force's two-stage show of force in April and October 2024 successfully neutralized all Iranian long-range SAM systems in just two airstrike operations.[231] The US military has continuously maintained its capabilities in this domain, in contrast to other NATO air

231. T. Newdick, "Israeli Strikes Knocked Out All of Iran's S-300 Air Defense Systems: Officials", *The War Zone*, October 28, 2024, available at: www.twz.com.

forces, which largely abandoned it during the 1990s and 2000s until the arrival of the F-35 in Europe.

However, achieving control of the air will require a deliberate and restrained application of SEAD. A slow, attritional campaign aimed at gradually rolling back the opposing IADS would ultimately play in favor of the post-Soviet doctrine by preventing air power from generating effects in support of broader operative or strategic objectives.[232] By contrast, a more effective approach could involve a series of partial, temporary neutralizations of key components of the IADS. This would fragment and disrupt the system enough to make its final neutralization—which remains the ultimate objective—resemble a series of engagements against individual GBAD units. As demonstrated in Iraq in 1991, the center of gravity of an IADS is its integration, not the sum of its individual systems.

SEAD operations in the near future will require the involvement of all components in a resolutely multi-domain operational approach.[233] Neutralizing an IADS must be conceived as a joint operation, with real-time targeting as the primary capability to be achieved. Alongside traditional air-to-ground effects, other assets can be employed in the enemy's depth, provided they can be deployed within the required time frame and without excessive risk. Such assets include special forces, cyber attacks,[234] space-based effects (particularly for intelligence and communications), and information operations.

Three broad operational scenarios can be outlined to illustrate the future of SEAD in the coming decades, which will be characterized by the extensive use of unmanned collaborative platforms serving as both decoys and effectors and supported by a coordinated offensive electronic warfare effort:[235]

- The neutralization of long-range SAM systems, surveillance radars, and IADS C2 centers through the use of long-range strike assets, such as stealthy, ballistic, or hypersonic cruise missiles, alongside saturation salvos of hundreds of OWA munitions launched from standoff platforms in the air, on land, or at sea. Their penetration would be supported by decoys and the suppression of medium- and short-range SAMs along the flight path.
- The neutralization of medium- and short-range SAM systems using stand-in weapons launched from within the adversary's engagement envelope, delivered by penetrating VLO platforms or through saturation salvos. The traditional US doctrine of preemptive fire remains a viable pursuit but demands substantial quantities of complex munitions.

232. Research interview with senior officers of the French Air and Space Force.
233. Research interview with senior officers of the French Army and Navy.
234. J. Bronk, "Modern Russian and Chinese Integrated Air Defence Systems: The Nature of the Threat, Growth Trajectory and Western Options", op. cit., p. 28.
235. Research interview with senior officers of the French Air and Space Force.

- The neutralization of SAM systems across all categories through the employment of other force components, including land artillery and naval gunfire support, special operations forces, and attack helicopters.

These scenarios will depend on a highly effective kill chain—specifically the Find, Fix, Track, Target, Engage, Assess (F2T2EA) process—relying heavily on real-time targeting and geolocation of enemy SAM systems and radars. To effectively neutralize these threats, the SEAD weapons developed over the next decade will need to match the performance, mobility, and distribution capabilities of modern IADS. This requirement imposes four key characteristics on future SEAD systems, characteristics that are only marginally compatible with one another:

- A flight time shorter than the redeployment time of enemy SAM systems, which favors the use of high-supersonic, ballistic, or hypersonic weapons.
- The ability to receive in-flight updates on target location, via direct data link, satellite communication, or VHA relay platforms. This is especially critical for long-range cruise weapons.
- The ability to autonomously detect, identify, and engage targets in the event of communications jamming, which requires the ability to loiter over adversary-controlled territory and employ onboard or collaborative sensor suites.
- The ability to evade enemy air defenses. This is achievable through a range of methods, including speed, maneuverability, radar stealth, very low-altitude flight, or saturation through numbers. The diversification of flight profiles and integration of swarm technologies[236] and decoys[237] can present a sustained tactical dilemma for IADS operators.

In the absence of these dedicated weapons, the attrition of adversary GBAD systems is still possible using certain existing munitions, provided they are integrated into an effective F2T2EA chain and capable of operating in a stand-in role. A notable example is the Israeli Air Force's use of GBU-39 GPS-guided bombs launched from F-35I Adir aircraft to strike Syrian SAM systems. This was made possible by the F-35's VLO stealth characteristics, the precision of coordinate extraction via radar mapping, and high-quality cooperative ELINT sensors.[238]

In the current tactical environment, low altitudes are effectively denied to the sustained presence of air power, while medium and high altitudes are increasingly contested, not only by enemy fighter aircraft but, more critically, by the enemy IADS. The capability and doctrinal trajectories pursued by Western armed forces since 1991 must evolve if they are to retain any chance of achieving rapid and decisive air dominance. Finally, the most pressing

236. T. Radtka, "Essaims et combat collaboratif. La saturation à l'ère de l'Intelligence artificielle", *Briefing de l'Ifri*, Ifri, July 16, 2024, available at: www.ifri.org.
237. T. Newdick, "ADM-160 Miniature Air Launched Decoy Spotted on Ukrainian MiG-29", op. cit.
238. Research interview with senior officers of the French Air and Space Force.

need is to embrace mass and saturation, principles that underpinned successful air power operations throughout the twentieth century.

## New approaches to air superiority

In 1945, the Japanese battleship *Yamato* was the most heavily armed and armored warship in the world, the culmination of an evolution in capabilities that had begun during the American Civil War and which saw the advent, proliferation, and eventual decline of battleships in modern navies. Only two ships of its class were ever built, and they had little impact on the course of the Pacific War. The *Yamato* fired its main guns only once in combat, during the inconclusive Battle off Samar.[239] It was ultimately sunk on April 7, 1945, by several hundred United States Navy carrier-based aircraft, each of which was, on its own, far inferior in firepower to the *Yamato* and vulnerable to its anti-aircraft defenses. Their combined mass and saturation, however, rendered the battleship defenseless and unable to absorb the damage inflicted on it.

The replacement of the battleship by the aircraft carrier as the dominant instrument of naval superiority illustrates a fundamental shift in the value of a weapons system—from the platform itself (the ship) to the mass-produced, remotely deployed effectors (the aircraft), capable of saturating the adversary and circumventing its firepower. This historical transition is instructive for understanding the current position of Western air forces in the fifth-generation era. It underscores the need for a paradigm shift: moving from a platform-centric mindset to one focused on sensors, weapons, and connectivity.

### *A shift in capabilities: From a performance-based logic to a saturation-based logic*

Since 1945, the cost of acquiring and sustaining Western weapons systems has consistently outpaced inflation, GDP growth, and defense budget increases. This trend, first observed by the industrialist Norman Augustine with respect to fighter aircraft, poses a medium-term structural risk to the air forces of all Western nations. "Augustine's Law", as it has become known, is projected to materialize with the next generation of equipment, which will succeed the platforms in service in the 2020s.[240]

239. "The Battle Off Samar: The Sacrifice of 'Taffy 3'", Naval History and Heritage Command, October 31, 2019, available at: [www.history.navy.mil](http://www.history.navy.mil).
240. N. Augustine, *Augustine's Laws*, American Institute of Aeronautics and Astronautics, 1997.

## Restoring a coherent mass of combat aircraft

A direct consequence of rising acquisition and ownership costs has been the steady decline in the size of combat aircraft fleets and complex weapons systems across Western armed forces. This trend has accelerated since the end of the Cold War. For example, the number of French fighter aircraft shrank by two-thirds between 1991 and 2024.[241] Likewise, Denmark is replacing its fleet of 50 F-16AMs with just 27 F-35As. While the rationale behind this downsizing is to prioritize the tactical performance of each platform, this approach no longer provides sufficient mass to ensure air superiority at the theater level. The "hypothesis of major engagement" included in France's 2024–2030 Military Programming Law envisages the deployment of just 40 fighters from the Air and Space Force.[242] This number is insufficient to overcome a modern, multi-layered IADS.[243] Moreover, this assumption represents 20% of France's total fighter fleet—an optimistic projection given the current force structure, particularly in a strategic context where homeland air defense and the continuity of nuclear deterrence would take precedence over extraterritorial commitments, as will be discussed in the final section.

In a budgetary environment constrained by the state of public finances, significantly increasing the number of manned combat platforms appears unlikely.[244] However, recent advances in AI technologies now make it feasible to envision the deployment of unmanned combat platforms as a complement to traditional aircraft. These systems could generate localized and temporary mass of both sensors and effectors capable of operating in a stand-in role and saturating even the most advanced modern IADS.[245]

The fundamental characteristics of these systems—known as Remote Carriers (RCs) in France's Future Combat Air System (FCAS) program, and as Collaborative Combat Aircraft (CCAs) in the USAF—will need to be carefully optimized across several key parameters:

- aerodynamic performance;
- payload capacity;
- operational range;
- radar cross-section;

241. R. Briant, J.-B. Florant, and M. Pesqueur, "La masse dans les armées françaises: Un défi pour la haute intensité", *Focus stratégique*, No. 105, Ifri, June 2021, available at: www.ifri.org.
242. Rapport annexé à la Loi no. 2023-703 du 1er août 2023 relative à la programmation militaire pour les années 2024 à 2030 et portant diverses dispositions intéressant la défense, available at: www.legifrance.gouv.fr.
243. Research interviews with senior officers of the French Air and Space Force.
244. "France: Staff Concluding Statement of the 2024 Article IV Mission", International Monetary Fund, May 23, 2024, available at: www.imf.org.
245. M. A. Gunzinger, L. A. Stutzriem, and B. Sweetman, "The Need for Collaborative Combat Aircraft for Disruptive Air Warfare", Mitchell Institute, February 2024, available at: https://mitchellaerospacepower.org.

- connectivity capabilities;
- production time;
- unit cost.

France, in opting for a very high-end VLO combat drone to accompany the Rafale F5,[246] is taking the risk of adhering to an Augustinian logic of hyper-performance at the expense of mass, with a projected unit cost likely to exceed €100 million and procurement numbers that may only reach a few dozen under current defense spending levels.[247] By contrast, the USAF, in the face of the operational challenge posed by the PLAAF in the Western Pacific, has chosen to pursue combat drones with lower individual performance and LO stealth characteristics, but whose unit cost, while increasing, remains low enough to support the acquisition of several hundred partially expendable platforms.[248]

However, the operational employment of these CCAs depends on overcoming several technological and legal challenges. These include the robustness of data link networks between manned fighters and their accompanying unmanned systems, the development of coordinated "swarm" tactics,[249] and the political acceptability of delegating autonomous use of force deep inside the adversary IADS.[250] The United States has clearly taken the lead in this domain, as demonstrated by the proliferation of CCA prototypes and the focused development of air combat-specific AI under DARPA's Air Combat Evolution (ACE)[251] and Autonomous Air Combat Operations (AACO)[252] programs.

246. Statement by Sébastien Lecornu, Minister of the Armed Forces, on the Strategic Air Forces, in Saint-Dizier on October 8, 2024, available at: www.vie-publique.fr.
247. Research interview with senior officers of the French Air and Space Force.
248. I. Singh Bisht, "US Marines Flight Test XQ-58A Valkyrie with Link-16 Capabilities", *The Defense Post*, October 14, 2024, available at: https://thedefensepost.com; J. Trevithick, "Second Batch of Air Force CCA Drones Could Be 20 to 30 Percent Pricier Than the First", *The War Zone*, January 10, 2025, available at: www.twz.com.
249. T. Radtka, "Essaims et combat collaboratif. La saturation à l'ère de l'Intelligence artificielle", op. cit.
250. L. de Roucy-Rochegonde, *La Guerre à l'ère de l'intelligence artificielle*, Paris: PUF, 2024.
251. S. Losey, "US Air Force Stages Dogfights with AI-flown Fighter Jet", *Defense News*, April 19, 2024, available at: www.defensenews.com.
252. "DOD Artificial Intelligence Agents Successfully Pilot Fighter Jet", Air Force Research Laboratory Public Affairs, February 13, 2023, available at: www.afrl.af.mil.

### Table 5: US CCA programs in early 2025

| | Manufacturer | Range of action | Cruising speed | Payload | Unit cost |
|---|---|---|---|---|---|
| **XQ-58 Valkyrie** | Kratos | 2,500 km | M 0.72 | 545 kg | $4–6 million |
| **UTAP-22 Mako** | Kratos | 1,200 km | M 0.90 | 610 kg | $2–3 million |
| **XQ-67** | General Atomics | Unknown | | | |
| **MQ-28 Ghost Bat** | Boeing | 1,850 km | High subsonic | 500 kg | $8–10 million |
| **Fury** | Anduril | Unknown | High subsonic | Unknown | $2–20 million |
| **Model 437 Vanguard** | Northrop Grumman | 2,800 km | M 0.85 | 950 kg | $5–6 million |

*Sources: "Valkyrie XQ-58A Fact Sheet", Kratos, 2024; "UTAP-22 Mako Fact Sheet", Kratos, 2024; "MQ-28A Ghost Bat Unmanned Aircraft, Australia", Airforce Technology, June 22, 2023; M. Davis, "Next Steps for the Ghost Bat", The Strategist, Australian Strategic Policy Institute, February 12, 2024; J A. Tirpak, "Northrop Touts Value of Digital Engineering as It Announces First Flight of Model 437", Air & Space Forces Magazine, August 30, 2024; J. Trevithick and T. Rogoway, "The Rise of Fury", The War Zone, September 11, 2023.*

## Saturation munitions

The issue of mass is arguably even more important in the domain of munitions, where two distinct challenges must be addressed.

The first relates to engagements against major powers, where the number of targets that must be neutralized to achieve air superiority is extremely high—estimated in the tens of thousands. This represents a dramatic shift from the asymmetric conflicts of the 2000s and 2010s.[253]

Second, the number of munitions required to neutralize each target is increasing as a result both of the growing sophistication of modern missile defenses, which can intercept a significant proportion of incoming weapons before they reach their targets, and of the implementation of passive defense measures by the adversary. The trend observed in Ukraine regarding long-range strikes indicates that the number of munitions needed per target has been consistently underestimated by a factor of approximately three.[254]

In light of these two trends, relying exclusively on a small number of high-performance standoff weapons is no longer sufficient to achieve air superiority or to leverage it effectively in support of other domains and operational environments. It is becoming increasingly clear that dedicated resources are

253. M. A. Gunzinger, "Affordable Mass: The Need for a Cost-Effective PGM Mix for Great Power Conflict", *Policy Paper*, Vol. 31, Mitchell Institute, November 2021, available at: https://mitchellaerospacepower.org.
254. J. Watling, "Long-range Precision Fires in the Russo-Ukrainian War", op. cit., p. 74.

needed to support these high-performance weapons in penetrating an enemy GBAD system.

Achieving and maintaining control of the air in a high-intensity conflict will therefore also depend on saturation weaponry to overwhelm the detection, tracking, and engagement capacities of enemy IADS and to counter passive defense measures. Such saturation strategies would put adversaries in an economic dilemma by forcing them to expend high-cost interceptors against low-cost but threatening targets. As previously discussed, this logic of capability diversification creates a virtuous cycle in saturating enemy defenses by introducing detection and identification challenges. A variety of flight profiles converging on the same target area is more effective than an equivalent number of munitions of a single, predictable type.

A potential solution therefore lies in adopting a comprehensive high-low mix of munitions. This would include a high-end segment composed of cruise missiles, ballistic missiles, and hypersonic weapons[255] alongside a more affordable segment of simple, mass-producible standoff munitions such as Iran's Shahed-136, as well as airborne decoys that can accompany high-end weapons, like the American ADM-160 MALD. However, such an expansion of the munitions arsenal would carry significant human resource implications for Western air forces, which already face persistent challenges in recruiting and retaining specialists.

## *A shift in tactics: From direct air-to-air confrontation to circumvention strategies*

Since 1945, the pursuit of air superiority at both the strategic and operative levels has been viewed by Western nations as a matter of force-on-force engagements, whether in symmetric or asymmetric contexts, with a historical preference for direct confrontation. However, the evolution of threats and the decline in the size of Western air fleets now cast doubt on the viability of achieving air superiority through direct air attack alone. Success will increasingly depend on adopting the kinds of circumvention tactics that are widely used by other nations and which are already integrated into NATO doctrine.[256] Among these, low-altitude penetration, surprise and deception, and Multi-Domain Operations (MDO) targeting stand out as some of the most promising avenues for achieving air superiority.

As a first approach, tactical circumvention can be achieved through the combination of low altitude and high speed. Gaining air superiority does not necessarily require a head-on attack against an enemy IADS using a composite air operation (COMAO) of 80 fighters flying at medium or high

255. A. Gorremans, "Hypervélocité: Rupture technologique ou effet de mode?", in *Année de la défense nationale 2025*, IHEDN, 2024, available at: https://shs.cairn.info.
256. Allied Joint Publication 3.3, Edition B, Version 1.

altitude. In reality, IADS networks are not uniformly distributed and are inherently shaped by geography. Very low-level penetration, an area of expertise still maintained by France and employed by both sides in Ukraine,[257] remains a viable tactic for striking targets within the coverage area of long-range SAM systems. While such operations are extremely risky in daylight—as demonstrated by the French Jaguar raid on Al-Jaber Air Base in Iraq on January 17, 1991[258]—they remain highly relevant at night or in poor weather, when the effectiveness of enemy short-range air defense (SHORAD) systems is reduced.

Tactical surprise and deception also remain critical enablers of success. No IADS operates with perfect consistency: Its circadian rhythm and ability to maintain an alert posture fluctuate over time. The essence of tactical surprise lies in attacking where the adversary least expects, feigning intent, forcing the adversary to launch its alert combat aircraft and then striking once they have returned to base, etc. These tactics have not been used much in Ukraine since the summer of 2022, largely because of the limited force structure of the Ukrainian Air Force and the doctrinal rigidity of the VKS. However, such approaches remain integral to Western doctrine and practice. A notable example is the opening strike of Operation Desert Storm, on January 17, 1991, which combined overwhelming firepower with ruse and surprise enabled by an extensive information warfare and deception campaign.[259]

Ultimately, to avoid falling into the trap of Russian and Chinese counter-strategies, the targeting of the adversary IADS must be guided by a systemic analysis of centers of gravity,[260] rather than the expected brute-force rollback approach, with its high cost in time, lives, and materiel. Achieving surprise destruction of an enemy's air and strike forces in its rear areas, as in the Six-Day War in 1967, is no longer a realistic prospect against a modern IADS. Instead, a more selective and deliberate targeting process is required, one shaped by an approach focused on generating operational effects rather than systemic target destruction. This is the antithesis of Russia's approach to targeting in Ukraine since February 24, 2022.[261] Crucially, this pursuit of effects must be coordinated across multiple domains and leverage all means available to circumvent and neutralize the adversary's IADS firepower.

- Ground forces, particularly special operations units and mechanized formations, can assault or maintain surveillance on overexposed physical targets—such as air bases or radar sites—provided they are already deployed in-theater and can operate without exposing themselves to enemy air power.[262] Additionally, ground-based artillery (particularly

257. Research interviews with Ukrainian Air Force officers.
258. R. Feeser, "Guerre du Golfe/Attaque sur Al Jaber", *Blog Pilote de chasse*, January 16, 2021, available at: www.pilotedechasse.org.
259. B. S. Lambeth, "The Winning of Air Supremacy in Operation Desert Storm", op. cit.
260. J. A. Warden III, "The Enemy as a System", op. cit.
261. G. Plopsky and J. Bronk, "Russian SEAD Efforts During the Air War in Ukraine", op. cit., pp. 106–136.
262. U.S. Air Force Doctrine Publication 3-01, *Counterair Operations*, op. cit., p. 25.

ballistic artillery) and naval strike capabilities can be employed to destroy or compel the withdrawal of entire segments of an IADS.[263] This approach has been demonstrated by Ukrainian HIMARS and ATACMS strikes on Russian S-400 systems.[264]

- The naval domain offers opportunities to exploit geography by striking the enemy IADS from the coastline, thereby forcing the defender into a Poros-style dilemma:[265] whether to concentrate defenses against land-based forces, protect the coastline, or divide resources between the two—risking insufficient coverage on both fronts. Sea-launched cruise missile strikes are particularly well-suited for achieving tactical surprise, especially when launched from submarines or from aircraft operating in the maritime domain beyond the adversary's radar horizon.
- The contribution of space and VHA platforms to intelligence and communications has become increasingly vital as the extended range of modern SAM systems forces Western special mission aircraft to operate at the edge of their effective range: Hence the replacement of the American E-8C JSTARS fleet with space-based radar imaging capabilities.[266] As an air force general put it, "mastery of space is now critical to mastery of the skies".[267]
- Lastly, cyber operations can be used to exploit temporary vulnerabilities within an adversary's IADS. However, offensive cyber actions are constrained by the long lead times required to generate effects and the rapid development of countermeasures by the adversary. A cyber weapon is comparable to a single-shot gun. While operations like Operation Orchard in 2008 demonstrate the potential for success, they should not lead to an overestimation of cyber attacks' potential role in SEAD operations.[268] Electronic warfare remains a far more fundamental capability for achieving air superiority.

### *Toward distributed C2*

Finally, the third category of solutions for ensuring air superiority lies in the resilience of C2 for air operations. In the face of adversary firepower and the inherently porous nature of IADS, achieving air superiority will require Western air forces to shift their philosophy toward distributed C2.

263. Ibid., p. 26.
264. J. Watling, "Long-range Precision Fires in the Russo-Ukrainian War", op. cit., pp. 106–136.
265. J. F. C. Fuller, *The Generalship of Alexander the Great*, Boston: Da Capo Press, 1960, pp. 180–199.
266. T. Newdick, "E-8 JSTARS Has Flown Its Last Operational Mission", *The War Zone*, September 26, 2023, available at: www.twz.com.
267. Research interview with a general officer of the French Air and Space Force.
268. F. A. H. Pedersen and J. T. Jacobsen, "Narrow Windows of Opportunity: The Limited Utility of Cyber Operations in War", *Journal of Cybersecurity*, Vol. 10, No. 1, August 5, 2024.

The highly centralized C2 model that has dominated since the 1980s lies at the core of NATO air doctrine.[269] This model, which is valued for its operational efficiency, was developed in a context where physical command centers were considered secure, at least until the late 2010s. Western tactical air command hubs, known as Combined Air Operations Centers (CAOCs), are indeed powerful tools for orchestrating air campaigns. However, they assume that the rear area is invulnerable. On a daily basis, CAOCs generate two critical documents for air units: the airspace control order (ACO), which defines the structure and management of airspace during wartime, and the air tasking order (ATO), which assigns specific missions to the various units participating in the air operation.

In the current C2 model, conducting operations without ATOs and ACOs is virtually unthinkable except in the most extreme emergencies, as doing so would carry a high risk of fratricide and operational confusion. However, with the proliferation of deep-strike capabilities, both the CAOCs themselves and the communications infrastructure required to distribute orders and consolidate unit reports are increasingly vulnerable to a rapid degradation of C2 functionality.

One way to mitigate the impact of deep precision strikes on the air command infrastructure is through the "continental dispersion"[270] of command functions. This involves delegating authority to tactical units, with mission command as the underlying conceptual foundation. This paradigm shift is central to the United States Department of Defense's Joint All-Domain Command and Control (JADC2) strategy,[271] which aims to integrate United States Army air defense assets with USAF C2 structures, while also enabling isolated units, particularly those stationed on Pacific bases, to remain operational even after Chinese ballistic missile strikes on their C2 assets. However, practical and organizational solutions for implementing distributed C2 remain underdeveloped. Progress is hindered by the entrenched culture of centralized command among Western air forces, their reliance on tight coordination for both effects and airspace management, and the lack of secure, mobile communications infrastructure.

Among the potential solutions, the most realistic ones involve reconsidering the centralized nature of the ATO. However, this poses significant challenges in terms of coordination and deconfliction. Two options, broadly speaking, are therefore conceivable: either to retain a degree of centralization or to regionalize airspace management. As it stands, this paradigm shift remains largely rhetorical within NATO air forces.

269. Allied Joint Publication 3.3, Edition B, Version 1, pp. 1-5-1-6.
270. Research interview with a general officer of the French Air and Space Force.
271. D. Deptula, "Making Joint All Domain Command and Control a Reality", *War on the Rocks*, December 9, 2022, available at: https://warontherocks.com.

# Technological solutions

In the future operating environment, as throughout the history of military aviation, achieving control of the air will continue to depend on technological adaptation. By the late 2020s, the primary challenge will be transitioning from a platform-centric, capital- and R&D-intensive model to a sensor- and weapon-centric model aligned with the logic of collaborative combat, with a relatively agnostic view of the platform carrying those sensors and weapons. The difficulty of this paradigm shift should not be underestimated, particularly in Western defense cultures that, since the Cold War and the Second Offset Strategy,[272] have focused on producing ever more advanced and capable generations of combat aircraft. Looking ahead, three technological domains are likely to prove decisive in the struggle for air superiority over the coming decades: counter-stealth radar technologies; developing a modern, differentiated IADS; and enhancing the survivability of complex platforms.

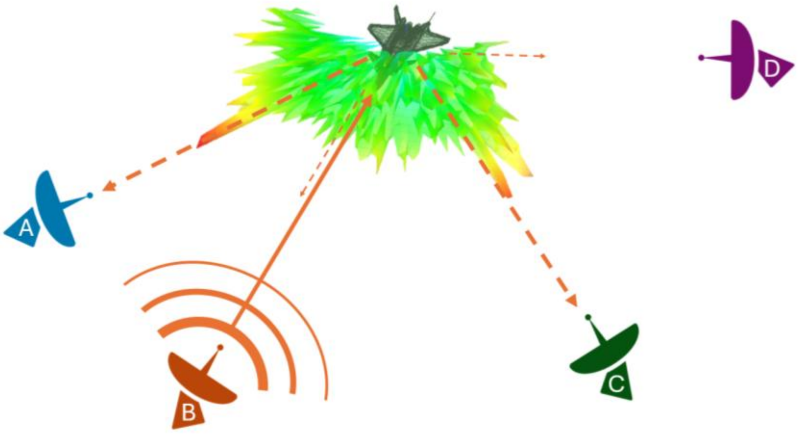
## *Detecting and countering X-band stealth*

Potential adversaries in the Western strategic environment already possess LO technology, and given the incremental upgrades observed across various iterations of the J-20, China is likely to field VLO platforms by the 2030s.[273] The first major challenge for Western air forces and GBAD systems will therefore be the ability to detect enemy aircraft at engagement ranges compatible with the reach of the enemy's missiles. A particular vulnerability lies in the terminal guidance phase, where the radar seekers of missiles targeting VLO aircraft will struggle to acquire lock. This challenge underscores the need for multi-mode seekers.

The first and most straightforward solution lies in the continuous improvement of radar systems. In the X-band, where most fire-control radars operate, AESA technology, when pushed to its limits in terms of transmission power, can partially counter LO stealth, but not VLO stealth.[274] Shifting to other frequency bands, such as L-band or VHF, presents two significant challenges for airborne radars. First, antenna size increases with wavelength, which makes it difficult to integrate such systems into the limited space available on fighters or combat drones. Second, spatial resolution deteriorates at longer wavelengths, which results in insufficient track quality for weapons guidance in L-band or VHF, even if these bands may reduce the search burden on X-band fire-control radars when coupled together.[275]

272. R. Grant, "The Second Offset", *Air & Space Forces Magazine*, July 24, 2016.
273. T. Newdick, "First Flight for China's H-20 Stealth Bomber Could Be Imminent: Report", *The War Zone*, July 8, 2022, available at: www.twz.com.
274. Research interview with senior officers of the French Air and Space Force.
275. "Would China's J-20 or Russia's Su-57 Fighter Win a Dogfight?", *The National Interest*, December 25, 2021, available at: https://nationalinterest.org.

**Figure 8: Multistatic radar operating principle**




Radar B's emissions, though reflected by the target, are too attenuated to be detected by radars B and D. However, they are successfully received by radars A and C—effectively neutralizing the target's LO stealth characteristics.

*Source: A. Gorremans, with VuVuZela (pseudo), "J-20 Radar Scattering Simulation", November 27, 2022, available at: https://basicsaboutaerodynamicsandavionics.com.*

Another radar-based solution is the multistatic approach, which involves separating radar transmitters from their receivers to circumvent the stealth geometries of VLO aircraft and mitigate the effects of directional jamming. This highly promising technology, which is operational in Russia under the designation 52E6MU Struna-1MU,[276] requires space-time synchronization between transmitters and receivers, which currently restricts its deployment to fixed ground-based sites. As a result, these systems remain highly vulnerable to enemy strikes.

A variant of the multistatic radar concept is passive radar, which opportunistically exploits electromagnetic emissions from the civilian environment, such as cell phone networks or FM radio, to detect aircraft that disrupt these electromagnetic fields. This concept, which has been operational since 2005 with Thales's Homeland Alerter 100, is particularly well-suited for defensive tactical operations in densely populated regions with a high density of transmitters, such as in Europe. However, its effectiveness is significantly reduced in maritime or desert environments.

Outside the radar spectrum, optronic systems operating in the infrared, visible, and ultraviolet bands are, by definition, insensitive to radar stealth. Several countries that lag behind in LO/VLO technology have instead invested in optronic sensors for their fighter aircraft, starting with the Soviet Union in the 1980s and later France in the 2000s. As of 2025, no infrared detection system has demonstrated the ability to detect VLO aircraft at tactically relevant ranges. However, the TV-Laser optronic tracking system integrated into the Rafale's IRST system makes it possible

276. K. Zikidis, A. Skondras, and C. Tokas, "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies", op. cit., p. 148.

to engage stealth targets with complete electromagnetic discretion. That said, optronic systems suffer from a significant and unavoidable limitation: Their performance depends on atmospheric conditions, making them a clear-sky solution only.

### Figure 6: Onboard systems vulnerable to enemy ELINT and the operational impact of associated EMCON measures

| System category | Operational impact of system EMCON |
|---|---|
| **Multi-mode radar** | Loss of radar detection<br>Air-to-air engagement dependent on off-board sensors<br>No aircraft-to-missile link: reduced effectiveness of air-to-air weapons |
| **Terrain-following radar** | Loss of low-altitude penetration capability in adverse weather (except digital terrain model terrain-following) |
| **Transponders** | Degraded friend identification; increased risk of fratricide |
| **Omnidirectional collaborative data links** | Degraded collaborative tactics; reliance on radio communications |
| **Radio** | Loss of short-range tactical communications |
| **SATCOM** | Loss of long-range communications |

*Source: Author's operational experience.*

Finally, the passive detection of adversary emissions, known as electronic support measures (ESM) or ELINT, aims to detect, identify, and track radar transmitters and communications, including data links and transponders on enemy aircraft. This approach offers three key advantages. First, unlike optronic systems, it is completely independent of weather conditions. Second, for a given antenna size, it can detect enemy transmissions at twice the range of its own emitting systems. Third, it compels adversaries who are aware of friendly ESM capabilities to adopt emission control (EMCON) measures, thereby degrading their own operational capability.

In the medium term, the most promising approach to countering radar stealth lies in compensating for the reduced detection range of onboard radars with AI-based sensor fusion and collaborative operations across multiple sensor types operating at different wavelengths. Instead of merely exchanging processed tracks, platforms would share raw, unprocessed sensor data. Provided that directional tactical data links—comparable to the F-35's Multifunction Advanced Data Link (MADL) but with significantly greater throughput—are widely implemented, it becomes feasible to extend this collaborative sensing capability across multiple platforms, thereby leveraging the advantages of multistatic sensor architectures.[277]

277. Research interviews with senior officers of the French Air and Space Force and defense industry executives.

### *Protection: Investing in differentiated ground-based air defense*

The proliferation and diversification of deep precision strike capabilities jeopardize the Western defensive posture, which has traditionally been dominated by fighter aircraft. This posture—primarily built around defensive fighter patrols, supported by high-end GBAD and missile defense systems—now faces a series of tactical challenges that increasingly undermine its effectiveness:

- circumvention from above, using ballistic and hypersonic weapons that operate beyond the reach of defensive fighter aircraft;
- circumvention from below, through the use of drones, including platforms that are either too numerous or too small to be effectively intercepted by fighter aircraft or SAM systems;
- circumvention through value, as the unit cost of Western SAM systems continues to rise faster than the cost of adversary strike assets, creating an unfavorable economic equation;
- and force structure erosion, as the viability of this traditional defensive model is challenged by the decline in Western fighter fleet sizes,[278] which are no longer large enough to provide sustained and robust air defense coverage.

Given these limitations, the only viable path to achieving defensive air superiority at the theater level is through substantial investment in a multi-layered air-to-air and GBAD system. This system must be capable of detecting, discriminating, and engaging both adversary platforms and airborne munitions. The operational and economic viability of such an IADS depends on several factors:

- The ability to calculate the impact points of ballistic trajectories and selectively engage only those threats targeting high-value assets, such as critical infrastructure or civilian populations—similar to the approach used by Israel's Iron Dome system.[279]
- The ability to detect and intercept a limited number of targets with extreme flight profiles (e.g., ballistic missiles, MaRV, or hypersonic glide vehicles) in order to defend friendly centers of gravity that cannot rely on passive defense. This capability requires the use of high-performance surveillance radars and advanced SAMs, each of which has a unit cost in

278. R. Briant, J.-B. Florant, and M. Pesqueur, "La masse dans les armées françaises: Un défi pour la haute intensité", op. cit.
279. T. Lister, "Israel's Iron Dome Doesn't Chase Every Rocket It Sees", *CNN*, May 18, 2021, available at: https://edition.cnn.com.

the order of several million euros,[280] and which are therefore available in limited numbers.

- The ability to detect and intercept high-subsonic or low-supersonic weapons flying at medium and low altitudes, such as cruise missiles or anti-ship munitions, at a controlled cost. This necessitates the deployment of medium-performance, highly mobile SAM systems. Because of their limited range, the operational effectiveness of these systems depends on achieving an economic balance that allows them to be procured in sufficient numbers to cover a meaningful area. This is currently not the case for most Western medium- and short-range SAM systems, whose unit costs range from €30 million to €200 million per battery and €500,000 to €1 million per missile[281]—with the notable exception of Israel's Iron Dome, whose interceptors cost around $50,000 per missile.[282]
- The ability to detect and neutralize large volumes of low-cost, long-range strike systems, such as the Shahed-131/136, across the entire depth of the rear area, while simultaneously providing terminal defense for key centers of gravity and critical nodes against a range of low- and medium-performance threats, from drones to cruise missiles. This requires a layered defense architecture composed of an effective low-altitude detection network, electronic jamming systems, short-range air defense (SHORAD) missile systems, and mobile, radar-guided AAA with a high rate of fire. In the case of AAA, caliber selection is crucial and must strike a balance between tactical effectiveness and the unit cost of munitions. This consideration is particularly relevant in the French context, where 40-mm systems are being introduced with munition costs ten times higher than those of 30-mm systems.[283]
- The ability to protect ground forces along the full length of the forward line of own troops, and to a sufficient depth (i.e., tens of kilometers), against threats such as enemy attack helicopters, drones, and remotely operated munitions. This layer of protection relies on many of the same systems as the previous category (e.g., MANPADS and AAA) but also requires the integration of anti-aircraft drones, such as the Coyote Anti-UAS.[284]

280. M. Gunzinger and B. Clark, "Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses", op. cit., pp. 75–76.
281. F. Hofmann, "Ukraine: Deutscher Nachschub für die Offensive", *DW*, May 12, 2023, available at: www.dw.com.
282. G. Grudo, "Iron Dome", *Air & Space Forces Magazine*, March 28, 2016, available at: www.airandspaceforces.com.
283. Research interview with senior officers of the French Air and Space Force.
284. J. Trevithick, "Drastic Increase in Army Coyote Drone Interceptor Purchase Plans", *The War Zone*, December 20, 2023, available at: www.twz.com.

These multiple constraints—validated by operational experience in Ukraine[285] since 2022 and by surface-to-air engagements in the Red Sea during the winter of 2023–2024[286]—support the case for an evolution of the current Western DCA model. They point to the need to strengthen GBAD capabilities at the lower end of the spectrum, particularly AAA, in both the land and naval domains.

Directed energy weapons may also play a role in the SHORAD architecture, particularly microwave weapons for countering drones.[287] However, the effectiveness of laser weapons against larger aerial targets remains unproven. While the economic appeal of laser-based intercepts is clear, no existing program worldwide has demonstrated a laser system powerful enough to replace AAA or MANPADS. The most advanced laser systems tested by the United States Navy and Israel deliver between 50 and 100 kilowatts of power,[288] which is barely enough to damage or disable a drone at short range, and only after several seconds of sustained tracking. Moreover, these systems typically weigh several hundred kilograms and occupy around 30 cubic meters of volume, making them ill-suited for mobile ground-based deployment.[289] Last but not least, lasers are ineffective in adverse weather conditions and would therefore require backup by conventional radar-guided AAA, which introduces capability redundancy—a difficult proposition in a context of fiscal constraint.

In conclusion, it is important to emphasize that a fighter component on defensive alert remains the most effective means of intercepting and neutralizing enemy aircraft before they can deliver their weapons. At the same time, no IADS, however advanced, can offer complete impermeability. This last point underscores the need to factor in the survivability of tactical assets and critical infrastructure as a fundamental prerequisite for achieving air superiority.

285. N. Pouzyreff and J.-L. Thiériot, "Rapport d'information en conclusion des travaux d'une mission flash, constituée le 18 octobre 2022 sur la défense sol-air en France et en Europe", Assemblée nationale, Commission de la défense nationale et des forces armées, February 15, 2023, p. 19, available at: www.assemblee-nationale.fr.

286. V. Groizeleau, "La Lorraine abat un drone houthi dans la région du détroit de Bal el-Mandeb", *Mer et Marine*, May 6, 2024, available at: www.meretmarine.com.

287. O. Parken, "THOR Microwave Anti-Drone System Downs Swarms in Test", *The War Zone*, May 19, 2023, available at: www.twz.com.

288. P. Gros, "Les armes à énergie dirigée", *Observatoire des conflits futurs*, Note No. 2, FRS, July 2018, p. 14.

289. Ibid., p. 11.

## *Improving the survivability of manned platforms*

Achieving air superiority requires thinking in terms of preserving critical resources, particularly when these assets are non-expendable by nature. This means keeping combat platforms in the air while they carry out their tactical missions.

Combat aircraft self-protection has been the focus of sustained development, even after the end of the Cold War. Continuous improvements have been made in jamming systems, radar warning receivers, and missile approach warning systems. The prevailing Western tactical consensus holds that once these platforms penetrate into enemy weapons' engagement zones to execute their missions, they cannot reliably neutralize or suppress all airborne or ground-based threats before coming under fire.[290] This limitation is largely due to the distributed capabilities of modern IADS. In this context, while the ability to remain undetected—and therefore radar and electromagnetic stealth—will continue to be a key factor for survivability and mission success, the ability to evade incoming fire through a combination of jamming, decoys, and evasive maneuvering remains essential.

This ability to survive enemy missile fire relies primarily on technology, but also on crew training and, for the foreseeable future, on the AI programming of those CCAs that will be non-expendable. However, this survivability remains highly speculative, given the combination of several significant uncertainties.

- The actual effectiveness of radar jamming and decoys can only be fully assessed when confronted with an adversary's wartime capabilities. Until tested in real combat, and despite the quality of Western technologies and training, certainty in this domain remains elusive.
- The kinematic performance of adversary missiles, which serves as a foundation for tactical planning, is based on estimates derived from inherently uncertain or incomplete intelligence.
- Last but not least—and this is one of the key lessons from the war in Ukraine—is the accelerating tempo of technological adaptation, particularly in electronic warfare, driven in part by the integration of AI in software development. A jamming program can be rendered obsolete in just a few weeks.

290. Research interviews with senior officers of the French Air and Space Force and anglophone air power specialists.

The fog of war therefore demands a high degree of caution when making a priori assessments about the survivability of air combat platforms. The experience of the Israel Defense Forces and their superiority complex in the air domain prior to October 6, 1973, serves as a powerful reminder of the need for strategic humility.[291]

The contest for air superiority is evolving into a more demanding and lethal struggle, characterized by two distinct patterns, each of which is associated with a specific altitude range. At medium and high altitudes (above 10,000 to 15,000 feet), the contest will be defined by increasingly symmetrical stealth capabilities and long-range engagements against the enemy's fighters and SEAD assets. At lower altitudes—the so-called "air littoral"—the battlespace will be densely saturated with munitions and various types of drones, while also being traversed by missiles and fourth-generation fighters attempting to penetrate the IADS. In both environments, victory will favor the force that successfully completes a dual transition: toward saturating mass, and toward an indirect approach, bypassing the adversary's traditional air power, supported by a distributed C2. The technological challenges related to stealth detection, GBAD, and platform survivability further reinforce the imperative to rely on remote sensors and effectors.

These considerations apply to all Western countries, including France, which is the focus of the section that follows and concludes this study.

291. P. Razoux, *La Guerre du Kippour d'octobre 1973*, Paris: Economica, 1999.

# *Timeline* – Deadlines and recommendations for the French Armed Forces

In this final section, France's ability to achieve air superiority is assessed through the lens of its strategic and capability objectives. The current French air power model, which is structured around the two sovereign functions of airspace defense and nuclear deterrence, is anchored in several major programs. The Rafale is its most emblematic platform, pending the introduction of the FCAS. However, this force model faces both qualitative limitations, including significant SEAD capability gaps, and quantitative shortfalls, notably insufficient fleet size and munitions stockpiles to endure a prolonged high-intensity conflict. The recommendations presented herein, which address both short-term operational needs and longer-term strategic planning, aim at mitigating the most urgent deficiencies. Ultimately, they call for a shift toward a high-low mix force structure that will enable the French Armed Forces to recover a credible mass.

## The current model and its evolution

The force structure of the French Armed Forces aligns with the broader Western paradigm of air supremacy, though it retains certain national specificities. The two primary operational missions—air defense of the metropolitan airspace and the permanent airborne component of nuclear deterrence—require the protection of all critical sites involved in nuclear force generation, the maintenance of a robust air defense alert posture over mainland France, and the ability to project air superiority in support of strategic nuclear strike missions. Beyond these core functions, the French Armed Forces must also be capable of protecting national interests and forces deployed abroad, while fulfilling France's alliance commitments and defense agreements, including conducting air operations in high-intensity conflicts.[292]

### *The French air order of battle in 2035*

In view of these operational mandates, the French Armed Forces' air order of battle between now and 2035 is subject to such severe budgetary, technological, human, and industrial constraints that it is possible, a decade in advance, to estimate its outline, under the current programming conditions (LPM 2024–2030) and if that programming is fully executed.

292. Rapport annexé à la Loi n° 2023-703 du 1er août 2023 relative à la programmation militaire pour les années 2024 à 2030 et portant diverses dispositions intéressant la défense.

## Table 7: French capabilities contributing to air superiority by 2035

| | Capabilities in 2035 (LPM) |
|---|---|
| **Fighter aircraft** | ~ 200 Rafale B/C/M to F4 and F5 standards<br>~ 25 Mirage 2000D RMV |
| **Combat drones** | A few VLO UCAVs |
| **Air-to-air refueling** | 15 A330 MRTT Phoenix |
| **Helicopters** | 70 Guépard HIL<br>67 Tigre |
| **Targeting** | 2 IRIS satellites |
| **AEW** | 4 future airborne early warning and control aircraft<br>3 E-2D Hawkeye[293] |
| **SIGINT** | 3 Archange<br>1 CELESTE space system |
| **Air-to-air missiles** | Meteor MLA<br>MICA NG |
| **SEAD** | RJ10 (FMAN) variant for SEAD mission<br>AASF variant configured for SEAD |
| **Long-range strike** | Upgraded SCALP<br>MDCN naval cruise missile<br>26 long-range rocket artillery systems |
| **Medium-range strike** | AASF<br>AASM (250 kg class)<br>AASM (1,000 kg class) |
| **Radar surveillance - national territory** | ~ 80 civil and military radars, integrated into the ACCS C2 system |
| **GBAD** | 12 SAMP/T NG systems<br>12 VL MICA systems<br>2 upgraded air defense frigates (FDA)<br>2 FREMM air defense vessels<br>6 FREMM and 5 FDI[294]<br>48 Serval Mistral<br>Mistral MANPADS |
| **Drone defense** | 40 Serval counter-drone units (LAD)<br>25 naval LAD systems<br>15 Parade systems |

*Sources: F. Giletti, Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2024, N° 1680, Assemblée nationale, October 26, 2023; J.-J. Ferrara, Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2022, Assemblée nationale, October 20, 2021; N. Gain, "Une ébauche de Serval LAD sur fond d'accélération", Forces Opérations Blog, August 15, 2023; research interviews with senior officers and general officers of the French Air and Space Force.*

293. Mainly dedicated to the carrier battle group's specific DCA.
294. FREMMs and FDIs are equipped with a very limited number of ASTER 15 missiles, mainly for self-protection, and contribute only marginally to air defense in a high-intensity conflict.

## *Weapons programs shaping air superiority*

As part of their ongoing modernization and response to evolving threats and operational environments, the French Armed Forces are engaged in several major capability development programs.

### The Rafale program and its weapons

Originally developed in the 1980s, the Rafale, a non-stealth multirole "4.5-generation" combat aircraft, is the only fighter currently in production in France. Between now and 2035, two standards of the Rafale will follow each other. The Rafale F4 will be deployed in three iterations: F4.1 in 2023, F4.2 in 2025, and F4.3 in 2027. This upgrade enhances the platform's combat systems, introducing improved radar capabilities, a new IRST optronic sensor, upgrades to the SPECTRA electronic warfare suite, and the integration of a helmet-mounted sight. Communications will be enhanced with SATCOM capability and Contact software-defined radio and data link. The 1,000-kg "Hammer" AASM (modular air-to-ground weapon) bomb is already operational on the F4.1, while the MICA NG will be integrated on the F4.3, featuring an air-to-air configuration of 8 missiles (compared with 6 on earlier standards). The Meteor is scheduled for a mid-life upgrade around 2031.

The critical milestone for the French Air and Space Force (AAE) is the Rafale F5, planned as part of the renewal of the airborne nuclear component (*composante nucléaire aéroportée*) (CNA) by 2035. In terms of air superiority, this major upgrade aims for several breakthrough capabilities:

- replacement of the RBE2 radar with the RBE2X, pushing AESA radar technology to its limits for advanced air-to-air detection;
- a new IRST with a detection range for LO/VLO aircraft that could be consistent with the range of adversary missile systems;
- sensor fusion and the ability to geolocate and engage enemy SAM systems, enabling credible SEAD;
- a renewed suite of air-to-ground munitions, including SEAD-specific capabilities;
- and enhanced resilience to jamming, via directional tactical data links and dual-constellation satellite navigation (GPS and Galileo).

However, by 2035, the Rafale F5 will be confronted with distributed, multi-layered IADS, supported by airborne early warning and surveillance assets, whose combined performance will make penetration extremely difficult, even at very low altitudes.[295]

295. Research interview with general officers of the French Air and Space Force.

## A UCAV for 2035?

In addition to the Rafale, France is developing an unmanned stealth collaborative combat aircraft intended to "punch a hole in the IADS for a less stealthy fighter to strike the target".[296] This loyal-wingman-type platform, officially announced on October 7, 2024, by the minister of the armed forces, and prefigured by Dassault Aviation's nEUROn (launched in 2003 with a prototype in 2012), will need to address several tactical challenges that heavily constrain its design:

- It will have to compensate for the Rafale's lack of radar stealth with VLO capability, which requires sufficient size to carry weapons internally.
- It must be capable of operating in a contested electromagnetic environment, which implies a high-performance onboard sensor suite and decision-making autonomy for flight paths—although any engagement will remain subject to human authorization.[297]

Given these constraints, the UCAV will likely be comparable to a traditional fighter aircraft in terms of size, capabilities, and therefore unit cost. As a result, it will not be expendable, but rather a scarce resource.[298]

## The Future Combat Air System

The FCAS project is a French-led capability initiative, part of which—the Next Generation Weapon System (NGWS)—was initiated at the political level in 2017 within the framework of the Franco-German Defence and Security Council. It is being developed jointly with Germany and, since December 2020, with Spain.[299]

This system of systems, which is expected to enter service by 2040, will be built around two types of assets: a sixth-generation stealth manned fighter, known as the New Generation Fighter (NGF), which forms the core of the program; and a family of drones, referred to as Remote Carriers (RCs), designed to operate in concert with the NGF in a collaborative Combat Cloud. The project architecture definition is scheduled for completion by summer 2025, ahead of a development and prototyping phase targeted for 2030.

296. Research interview with senior officers of the French Air and Space Force.
297. Research interview with senior officers of the French Air and Space Force.
298. Research interview with senior officers of the French Air and Space Force and an American air power specialist.
299. J. Möhring, "Troubled Twins: The FCAS and MGCS Weapon Systems and Franco-German Co-operation", *Études de l'Ifri*, Ifri, December 2023, available at: www.ifri.org.

### Table 8: FCAS project phasing

| | Period | Budget | Objectives |
|---|---|---|---|
| **Phase 1** | 2019–2021 | €260 million | Technological maturation<br>Refinement of operational concepts (from 10 to 5 candidate architectures) |
| **Phase 1B** | 2022–2025 | €3.6 billion | Simulation loops to refine operational concepts<br>Selection of a single architecture by the end of the phase |
| **Phase 2** | 2025–2029 | €4.5 billion | Development of stand-alone demonstrators for the NGF, RCs, and the Combat Cloud |
| **Phase 3** | 2030+ | ?? | Integration of demonstrators into a connected combat environment, in parallel with the development of operational platforms |

*Sources: Research interviews with senior officers of the French Air and Space Force leading the FCAS project.*

The operational scenarios envisioned for the NGWS architecture span the full spectrum of OCA (including SEAD) and DCA missions.[300] The project sets very ambitious technological goals, particularly for the NGF, which must feature stealth capabilities, be compatible with the size and weight of the ASN4G air-launched nuclear missile, and be adaptable for carrier-based operations.[301]

The project is structured around seven technological pillars, each led by a national industrial champion, with participation from industry partners in the two other member countries.

### Table 9: Industrial sharing of the FCAS project

| | Component | Industrial partners (prime contractor) |
|---|---|---|
| **Item 0** | Architecture development and arrangement of operational items | Dassault Aviation – Airbus GmbH – Indra (co-contractors) |
| **Pillar 1** | NGF demonstrator | Dassault Aviation - Airbus GmbH - Airbus SAU |

300. Research interviews with senior officers of the French Air and Space Force leading the FCAS project.
301. Research interviews with senior officers of the French Air and Space Force leading the FCAS project and with defense industry executives involved in the project.

| | | |
|---|---|---|
| **Pillar 2** | Engines | EUMET (joint venture: Safran - MTU) - ITP Aéro |
| **Pillar 3** | Remote Carrier demonstrators | Airbus GmbH - MBDA France - Satnus |
| **Pillar 4** | Combat Cloud | Airbus GmbH - Thales France - Indra |
| **Pillar 5** | Simulation | Airbus GmbH - Dassault Aviation - Indra |
| **Pillar 6** | Sensors | Indra - Thales France - FCMS |
| **Pillar 7** | Stealth | Airbus SAU - Dassault Aviation - Airbus GmbH |

*Source: Research interviews with senior officers of the French Air and Space Force leading the FCAS project.*

However, the project faces several critical vulnerabilities that raise legitimate concerns about its long-term viability.

Chief among them is its dependence on the continued political alignment of the three partner nations—particularly the Franco-German relationship, which is increasingly uncertain amid the current climate of political instability in both countries. The future of the NGWS, which was born of the joint initiative of Emmanuel Macron and Angela Merkel, has become less certain since Merkel's departure, and its trajectory could be significantly affected by the outcome of the French presidential elections in 2027.

While the operational requirements of the three participating armed forces appear broadly aligned, the industrial foundation of the program remains fragile. The NGWS project brings together competing defense contractors and depends on their ability to cooperate and share expertise and technologies. The distribution of prime contractor roles reveals underlying imbalances, most notably in Pillar 1 (the NGF stealth fighter demonstrator), where Dassault Aviation, the designated lead, is in the minority, holding only 33% representation alongside Airbus GmbH and Airbus Spain, which are two branches of the same company and direct competitors to Dassault in the 4.5-generation fighter market with the Eurofighter Typhoon. Furthermore, in some cases, prime contractor responsibilities have been assigned to firms with limited experience in the relevant domain, at the expense of established experts. For instance, in Pillar 6 (Sensors), the distribution appears to disadvantage Thales, the leading EU company in the field of air intercept radars and optronics.

The coherence of national commitments to the FCAS program is also being called into question, particularly in light of intermediate acquisition programs that may enter into budgetary competition with FCAS development in the 2030s. For example, Germany has procured 35 F-35A aircraft and has partnered with the United Kingdom on the development of a combat UCAV under the Trinity House Agreement.[302] Meanwhile, France is advancing the Rafale F5 standard for delivery by 2033, along with a stealth UCAV developed by Dassault Aviation—a platform that directly overlaps with the upper segment of the FCAS Remote Carriers, for which Airbus GmbH serves as the prime contractor.

In the end, the primary vulnerability of the FCAS project is budgetary, as the technological trajectory of the NGWS aligns closely with Augustine's Law. The NGF in particular represents a substantial leap in complexity. In the air-to-air domain, it will require performance comparable to the F-22A Raptor, whose unit cost stands at approximately $282 million (constant 2021 dollars),[303] but with additional constraints, including carrier compatibility and the ability to carry the ASN4G. It is therefore highly likely that the NGF's unit cost, which will be a function of its mass, will reach several hundred million euros, raising serious affordability concerns for all three partner nations, which are already struggling to sustain the force structure of their existing 4.5-generation fighter fleets. Moreover, the continuation of the FCAS program could be jeopardized by any major crisis happening between now and 2040, which should place significant strain on defense budgets.

Ultimately, the future of the FCAS project remains uncertain, despite the progress made during phases 1 and 1B. However, the work completed thus far remains sufficiently conceptual and non-binding to inform alternative capability strategies should the program fail to move forward by the end of the 2020s.

### GBAD systems

In addition to the VL MICA short-range system and the Mistral MANPADS, France's GBAD architecture is supported by three major development programs.

In the medium-range segment, the ASTER 30 Block 1 NT will provide the SAMP/T system with an autonomous anti-ballistic missile capability, while also enhancing its resilience against enemy electronic warfare. This upgrade is also planned for the French Navy's air defense frigates (FDAs) and will eventually include a mid-life upgrade of the FREMM DA frigates in the next LPM.[304]

302. C. Hoyle, "German F-35 Production Ready to Take Off as Lockheed Martin Eyes Further European Sales", *Flight Global*, June 9, 2024, available at: www.flightglobal.com; G. Allison, "Britain and Germany to Develop Combat Drones Together", *UK Defence Journal*, October 23, 2024, available at: https://ukdefencejournal.org.uk.

303. Author's calculation, based on research into Augustine's Law.

304. Research interview with a defense industry executive.

Anti-aircraft artillery, a capability shortfall within the French Armed Forces, has been the focus of renewed development through the Serval LAD project, which is specifically designed to enhance counter-drone protection for ground forces.[305]

Finally, in the hypervelocity defense segment, the TWISTER endoatmospheric interceptor program, conducted under the European Union's Permanent Structured Cooperation (PESCO) framework, is currently the subject of industrial competition. Two rival initiatives are in play: the EU HYDEF project, led by SENER Aeroespacial, and the HYDIS$^2$ project, coordinated by MBDA and supported by France, Italy, Germany, and the Netherlands.

In the event of a high-intensity conflict conducted independently against a regional power, the current structure of the French Armed Forces, supported by these major programs, would likely enable the attainment of a sufficient degree of air superiority to allow the other service branches to operate within an acceptable level of risk and attrition.[306] However, in the case of a major coalition engagement against a peer state, or in the event of a saturation attack by a hostile non-state actor employing asymmetric strike capabilities, the French posture would reveal significant capability gaps and human resource vulnerabilities.

## Vulnerabilities of the French force structure

Between 1991 and the mid-2010s, France abandoned several key technological domains, resulting in capability gaps at the high end of the air conflict spectrum. This has led some observers to argue that "France is now playing in NATO's second division".[307] At the same time, the progressive downsizing of the armed forces has eroded critical mass in domains where operational expertise is strong. The result is the emergence of token "Potemkin capabilities"[308] with insufficient organic depth.

### *Missing or obsolete key capabilities*

The French Armed Forces suffer from several qualitative gaps that are the result of either a failure to field capabilities, such as radar stealth and offensive electronic warfare, the outright abandonment of existing

305. N. Gain, "Une ébauche de Serval LAD sur fond d'accélération", *Forces Opérations Blog*, August 15, 2023, available at: www.forcesoperations.com.
306. The result of a wargame conducted by the Capability Development Office of the Air and Space Force Staff. This consensus was shared by several senior officers of the Air and Space Force in research interviews.
307. Research interview with a general officer of the French Air and Space Force.
308. Research interview with a retired general officer of the French Air and Space Force.

capabilities, such as SEAD, or gradual drawdowns driven by successive budget cuts, as seen in the areas of munitions and GBAD.

### The LO/VLO capability gap

In the realm of air-to-air combat, the French Air and Space Force is well-equipped and proficient when facing adversaries operating non-stealth fighter aircraft.[309] However, the current operational shortfall in VLO technology could make France reliant on partner air forces equipped with VLO platforms and effectively limit it to a supporting role in allied operations for the period 2025–2035.

There are several reasons for France's reluctance to invest in VLO technology. In the 1990s, both France's armed forces and its national defense industry were caught off guard by the rapid emergence of American VLO capabilities. Having already committed to the Rafale program, French defense stakeholders downplayed the significance of VLO technology in the context of the peace dividend and the limited scope of military operations at the time. Moreover, the rise of VLO platforms presented a commercial risk for the Rafale, with no alternative stealth design that could be rapidly developed in France. This strategic posture was further reinforced by the nature of the conflicts between 1995 and 2022, where the Rafale's capabilities consistently exceeded the operational demands of theaters in Afghanistan, Libya, and the Sahel.

The technological asymmetry is now clear. French pilots, who regularly participate in joint exercises against fifth-generation fighters, acknowledge that "combat missions against stealth aircraft in the Rafale are very difficult to win with the current state of sensors".[310] While radar stealth alone does not guarantee air superiority, it remains an undeniable advantage, especially in high-threat scenarios, unless one is prepared to accept high-risk, low-altitude penetration missions. Looking ahead, stealth capabilities may also become an entry requirement for front-line roles in coalition operations, serving as a marker of strategic influence and determining a nation's place in shaping coalition air power options.

In the event of a high-intensity conflict alongside Western allies, the French fighter fleet could be relegated to a supporting role behind fifth-generation platforms, forming part of a two-tier air coalition, where fourth-generation fighters still retain a fundamental role.[311]

309. Research interview with senior officers of the French Air and Space Force.
310. Research interview with senior officers of the French Air and Space Force.
311. Research interview with a retired general officer of the French Air and Space Force.

## SEAD

Alongside stealth, dynamic targeting and SEAD capabilities have become key bottlenecks in France's ability to achieve air superiority since the retirement of the AS37 Martel in 1997.[312]

France will not field a dedicated SEAD capability before the Rafale F5 enters service around 2035. While the AASM provides the Rafale with a limited DEAD capability against fixed, short-range SAM sites, its effectiveness remains heavily dependent on external sensors, which France does not yet possess. The challenge is similar when targeting long-range SAM systems: France's SCALP-EG cruise missiles, whose range is just sufficient to engage the most modern SAM systems in standoff mode, cannot be reprogrammed in flight, which limits their ability to engage mobile targets, unlike the American Tomahawk Land Attack Missiles (TLAM) Block IV and V. Moreover, acquiring a stopgap SEAD solution off-the-shelf poses serious challenges. Such a move would conflict with the short-term interests of the French defense industrial and technological base, which currently lacks an offering in this market segment.

Despite strategic concerns raised as early as 2014[313] and the lessons emerging from the Russo-Ukrainian war, France is effectively extending its strategic gamble into the period 2025–2035 by assuming that it will not need to confront a complex IADS on its own, except in the highly specific context of the nuclear deterrence mission.

## Controlling the electromagnetic spectrum

In the electromagnetic domain, which is critical to achieving modern air superiority, the French Armed Forces emerged from the Cold War with a capability strategy centered on the high quality of their defensive radar jamming systems. Operating independently of the United States and relying on internationally recognized expertise in defensive jamming, France chose not to invest in other key dimensions of electronic warfare. As a result, France has fallen behind in adapting to the growing operational capabilities that could be fielded against its armed forces, particularly in light of the following critical shortfalls:

- France has very few offensive electronic warfare systems at its disposal, despite the increasing resilience and complexity of adversary IADS. It also lacks any operational capability to jam enemy radar satellites.

312. P. Gros et al., "La neutralisation des défenses aériennes adverses (SEAD)", *Observatoire des conflits futurs*, FRS, April 29, 2021, available at: www.frstrategie.org; J.-C. Noël, M. Paglia, and É. Tenenbaum, "Les armées françaises face aux menaces anti-aériennes de nouvelle génération", *Focus stratégique*, No. 86, Ifri, December 2018, available at: www.ifri.org.

313. C. Brustlein, É. Tenenbaum, and É. de Durand, *La Suprématie aérienne en péril: Menaces et contre-stratégies à l'horizon 2030*, op. cit.

- The French Armed Forces do not have the equipment or capability to jam satellite-guided precision munitions, such as those fielded by Russian and Chinese forces.
- Link 16 and secure voice encrypted radio communications have still not been deployed in French detection and control centers, nearly a quarter century after their widespread adoption across the rest of NATO.
- France has no directional airborne communications system comparable to the F-35's MADL, which leaves it vulnerable to Russian SIGINT and jamming capabilities.

### Attrition and saturation munitions

The French Armed Forces primarily rely on high-tech air-delivered munitions, whose unit costs have steadily increased while stockpiles remain limited.

To address the volume and specific nature of targets associated with the OCA mission, the current French high-low mix lacks a low-complexity, low-cost standoff munition segment. France's entry force capabilities, built around a very limited inventory of SCALP cruise missiles, are not suited to confronting a Russian-style IADS. Although considerable efforts have been made to lower the unit cost of AASM precision-guided bombs to regain munition mass,[314] their range remains too short to support any operational scenario beyond stand-in employment.

Since ratifying the Oslo Convention on Cluster Munitions in 2010, France no longer possesses the capability to engage area targets dispersed over a wide surface. As a result, striking an airfield to destroy enemy aircraft on the ground can be achieved only through either the massive use of unitary standoff munitions to saturate parking areas or via stand-in delivery of opportunistic weapons guided by aircraft operating within range. However, France lacks both the necessary stockpile of standoff munitions for the first approach and a stand-in platform capable of deploying a large volume of simple munitions in a contested air environment.

### Ground-based air defense

In the GBAD mission, France's primary vulnerability lies in the weakness of its lower-tier defenses. The current system is no longer truly multi-layered, but at best two-layered, and it relies almost exclusively on high-end SAM systems, even for engaging low-cost, unsophisticated threats. France lacks cost-effective systems to handle masses of low-end threats such as OWA drones, which can saturate existing GBAD systems through sheer volume.

MANPADS may offer part of the solution, but their current distribution within the French Armed Forces raises concerns. At present, MANPADS are allocated only to protect land forces and for the close-in defense of select

314. Research interview with senior officers of the French Air and Space Force.

French Navy vessels. By contrast, French air bases, including those with a nuclear mission and forward-deployed bases, as well as first-rank frigates of the French Navy, are not protected in this segment.

The most significant capability gap is in AAA. This is a historically underdeveloped domain in France, despite its proven relevance in recent conflicts, particularly in Ukraine. As of 2024, France possesses no radar-guided AAA systems, with the sole exception of the 76-mm guns on its frigates, which are primarily intended for self-defense.

At the upper end of the threat spectrum, France lacks ballistic missile defense capabilities beyond terminal interception, currently limited to the ASTER 30 system. This shortfall is particularly concerning amid the widespread proliferation of conventional ballistic missile arsenals, as previously noted. The unrestrained use of such weapons by Russia in Ukraine and by Iran against Israel—a nuclear-armed state—challenges the assumption that nuclear deterrence alone provides a sufficient response to this class of threat.

These qualitative shortfalls render three tactical scenarios nearly unworkable: SEAD operations against a modern IADS, which is the highest operational priority; air-to-air combat against fifth-generation LO/VLO fighters; and defense against saturation attacks involving OWA munitions, as well as conventional ballistic and hypersonic missile salvos. In the event of a protracted high-intensity conflict, these limitations would be further aggravated by several quantitative vulnerabilities.

## *Lack of organic depth and mass*

Despite its national ambitions, detailed above, France's ability to achieve air superiority remains constrained as of 2025 by four critical capacity shortfalls: the size of the fighter fleet, ammunition stockpiles, the operational support fleet, and GBAD. These material limitations are further exacerbated by human resource challenges across all four domains.

### The structure of the French fighter fleet

As of 2024, the French fighter fleet, comprising 107 Rafales in the Air and Space Force and 41 in the French Navy, has reached its lowest level since 1916.[315] This trend is expected to continue as a result of the convergence of two factors:

- the planned retirement of the Mirage 2000-5F fleet by 2029, potentially adjusted based on aircraft transfers to Ukraine;
- and the sale of 24 second-hand Rafales to Greece and Croatia.

315. F. Giletti, *Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2024*, No. 1680, Assemblée nationale, October 26, 2023, available at: www.assemblee-nationale.fr.

As a compensatory measure, the delivery timeline for the 42 Rafales in Tranche 5 remains uncertain. The objective of reaching 225 multirole fighters by 2030, as outlined in the previous LPM,[316] now appears unrealistic. Although 48 Mirage 2000Ds are expected to remain in service, their mid-life upgrade did not add a credible air-to-air capability.

To illustrate the current "anemia" of the fighter fleet,[317] it is useful to reference a widely accepted empirical rule within NATO: Deploying one combat aircraft typically requires a total of 4 to 5 airframes, with the remainder cycling between maintenance and training. By 2030, the French Armed Forces will likely need to allocate approximately 5 squadrons of Rafales—around 100 aircraft—to cover the permanent air security posture (*posture permanente de sûreté aérienne*) (PPS-A) and the airborne nuclear deterrent.[318] This would leave only about 30 Rafales (across the Air Force and Navy) and approximately 10 Mirage 2000Ds (one-fifth of the remaining fleet) available for sustained operations in the event of a major conflict. Under these conditions, meeting the operational requirements outlined in the 2024–2030 LPM[319] for a major engagement scenario will be extremely challenging, particularly in a prolonged high-intensity conflict, and will likely remain so until the delivery of the fifth Rafale tranche.

In addition to this quantitative shortfall, the fighter fleet suffers from a capability imbalance driven by a persistent lack of mission-critical equipment, the acquisition of which is often treated as a budgetary adjustment variable within major procurement programs.[320] These include sensors—particularly AESA radars and IRST systems—as well as missile launch pylons and their associated interface systems.[321]

However, even with a fully equipped fighter fleet, the French air forces would face another critical capability bottleneck: the limited stockpile of complex munitions.

## Insufficient ammunition stockpiles

While France's stockpiles of basic air-to-ground munitions are considered to be at an acceptable level,[322] the situation is markedly different when it comes to complex, high-value munitions. As highlighted in a 2023 Senate report,

316. F. Parisot, "Le format de l'aviation de chasse de l'Armée de l'Air et de l'Espace: Une équation complexe à plusieurs variables", *Revue de défense nationale*, June 2023, available at: www.defnat.com.
317. Research interview with a general officer of the French Air and Space Force.
318. Author's calculation.
319. Rapport annexé à la Loi n° 2023-703 du 1er août 2023 relative à la programmation militaire pour les années 2024 à 2030 et portant diverses dispositions intéressant la défense, available at: www.legifrance.gouv.fr.
320. Research interview with senior officers of the French Air and Space Force.
321. J.-J. Ferrara, *Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2022*, Assemblée nationale, October 20, 2021, available at: www.assemblee-nationale.fr.
322. Research interview with a general officer of the French Air and Space Force.

"the ambition expressed by the Ministry of the Armed Forces regarding munitions remains far below the requirements of high-intensity combat".[323]

The expenditure rates for air-to-air missiles observed during large-scale exercises[324] and simulations,[325] when compared with actual stock levels as of 2024—and factoring in the need to preserve inventory for the PPS-A and the CNA—translate to an estimated three days of high-intensity combat, or as little as one day in the case of the Meteor missile.[326] This challenge is likely to worsen over time as the result of age-related limitations on missile service life.[327]

In the realm of standoff air-to-ground weapons and SAMs, the situation is even more critical. Transfers to Ukraine have drawn down SCALP and ASTER 30 stockpiles to the threshold of strategic reserves,[328] with restocking dependent on future procurement orders in an uncertain budgetary environment. The FMAN/FMC next-generation missile program, which received €473 million in funding under the 2024 draft budget law (PLF 2024)[329] and is not expected to reach operational capability until after 2030, highlights the budgetary tension between short-term munition replenishment and long-term investment in next-generation systems.

This issue is all the more critical in light of the success of Operation Hamilton in Syria in 2018,[330] which may have contributed to the dangerous illusion that a one-off precision strike using high-end air-to-ground munitions can decisively alter a strategic situation. In reality, achieving air superiority in a high-intensity conflict demands a prolonged effort, including the extensive use of standoff weapons over time.

### Ground-based air defense

Ground-based air defense remains the most neglected component of France's DCA capabilities, for both doctrinal and historical reasons. For decades, the need for DCA was treated as a contingency measure relevant only in the event of a failure in the OCA strategy. Furthermore, since the end of the Second World War, France and NATO countries have generally not

323. H. Saury and H. Conway-Mouret, *Rapport pour avis sur les crédits de l'équipement des forces (P146): Accélérer le passage à l'économie de guerre*, Avis nº 130 (2023-2024), Sénat, 2023, p. 4, available at: www.senat.fr.

324. Feedback from VOLFA exercises, discussed during a research interview with a general officer of the French Air and Space Force.

325. Author's simulations in support of a capability wargame conducted by the French Air and Space Force Staff.

326. J.-J. Ferrara, *Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2022*, Assemblée nationale, October 20, 2021, available at: www.assemblee-nationale.fr.

327. R. Briant, J.-B. Florant, and M. Pesqueur, "La masse dans les armées françaises: Un défi pour la haute intensité", op. cit., p. 35.

328. F. Alexandre and O. Fourt, "'Opération Chrysalide': Comment la France organise la livraison de missiles Scalp à l'Ukraine", RFI, May 6, 2024, available at: www.rfi.fr.

329. M. Belhamiti, *Avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finance pour 2024*, Assemblée nationale, October 26, 2023, available at: www.assemblee-nationale.fr.

330. E. Moyal, "L'opération Hamilton… démonstration stratégique et puissance aérienne", op. cit.

had to engage in sustained defensive air warfare, with the very particular exception of the Falklands War.

France's GBAD capabilities are currently sized to protect only the three air bases assigned to the nuclear deterrent—Saint-Dizier, Istres, and Avord—and to provide partial coverage for ground forces deployed in overseas operations. A residual capacity exists to support, in select cases, the defense of French air bases abroad or to deploy a temporary additional air defense envelope (*dispositifs particuliers de sûreté aérienne*; DPSA) above high-profile domestic events, such as the Paris Olympic Games in the summer of 2024.

The 2024–2030 LPM allocates €5 billion to strengthening France's GBAD. This includes the modernization of the 8 existing SAMP/T systems and the procurement of 4 additional units by 2035, along with 12 VL MICA systems. The plan also provides for the reinforcement of counter-drone capabilities and the establishment of an initial AAA capability.

Even under the optimistic scenario of full implementation of the LPM, these capabilities will remain limited in scale and focused on the high end of the spectrum:

- Counter-drone systems (LAD) will be barely adequate to protect the most critical sites, including select air bases in mainland France, one to two forward air bases (*bases aériennes projetées*; BAPs), and a portion of deployed ground forces. These systems would fall short in countering the scale and complexity of drone threats observed in Ukraine, particularly as a result of a shortfall in electronic warfare assets.
- All AAA remains assigned to the Army and Navy, which raises serious concerns about the lack of low-altitude defense for air bases.
- SAM systems will remain insufficient to simultaneously protect both key sites in mainland France and those supporting overseas operational deployments.

## Operational support fleets

Three categories of support aircraft are especially critical to the achievement of air superiority: AEW&C platforms, electronic intelligence (ELINT/SIGINT) aircraft, and air-to-air refueling tankers.

The ability to maintain continuous low-altitude surveillance over national territory without allied support during a prolonged crisis, as well as to rapidly deploy a permanent AEW&C capability to a theater of operations while simultaneously fulfilling the nuclear deterrence mission, remains an aspirational goal for France's E-3F AWACS fleet.

The French tanker fleet, initially sized to support the nuclear deterrence mission and later expanded with three additional aircraft to accommodate its dual role in air-to-air refueling and long-range airlift, remains under constant strain because of the demands of this operational versatility.

Finally, since the retirement of the C-160G Gabriel, the French Armed Forces no longer possess a dedicated airborne ELINT capability. This gap is only partially filled by the ELINT module on the E-3F AWACS, for real-time intelligence, and by the CERES space-based constellation and ASTAC pods on Mirage 2000Ds, for medium- and long-term intelligence. The planned acquisition of three Falcon 8X Archange aircraft by 2028 will not provide continuous ELINT coverage over the battlespace because these platforms will be divided between long-term intelligence—historically France's priority in the ELINT domain—and real-time intelligence, at least until the deployment of either quick-win VHA solutions or the launch of the CELESTE SIGINT constellation in 2029.

These capability shortfalls, whether the result of qualitative gaps or an insufficient force structure, should not overshadow France's human vulnerabilities, which are a result of the difficult strategic transition facing an armed forces shaped in part by two decades of counterinsurgency operations.

## *Human vulnerabilities*

The French Armed Forces enjoy a high level of operational prestige and a continuity of combat experience that is unique among European nations and which is the result of sustained involvement in overseas operations.

This experience, shaped by the expeditionary campaigns of the 2000s and 2010s in Afghanistan, the Sahel, and the Levant, has concentrated a portion of the air forces' expertise and left a lasting mark on current leadership.[331] On the one hand, the demands of nuclear deterrence have oriented France's air forces toward the most extreme end of the conflict spectrum. On the other, operational deployments have focused on the complex tasks of close air support and dynamic targeting typical of modern counterinsurgency conflicts—often at the expense of conventional high-intensity air superiority, although this was still practiced in training. This fragmentation of expertise, stemming from a departure from the integrated force model of the 1990s, has introduced vulnerabilities in training, readiness, and C2.

### Force training

In the field of training, which encompasses education, continuity training, and the development of new tactics, techniques, and procedures (TTPs), two conceptual weaknesses have become especially apparent in light of the war in Ukraine.

331. Research interview with a retired general officer of the French Air and Space Force.

French fighter pilot training has preserved several high-end competencies, despite an annual flight hour average that, at around 150 hours per pilot per year, falls slightly below the NATO standard of 180 hours.[332] Air-to-air combat with fourth-generation platforms and all-weather, very low-altitude penetration—a "cheap version of stealth"[333]—remain areas of excellence in which France ranks "among the top three in the world",[334] supported by regular participation in complex tactical exercises and advanced training programs such as the Qualified Weapons Instructor course.[335] The integration of the Meteor missile provides highly offensive capabilities despite the absence of stealth, placing the Rafale at the intersection of fourth- and fifth-generation systems. Interoperability with NATO, which is at the core of aircrew education and tactical training, also remains high.

However, the quality of this training suffers from the lack of a coherent doctrine defining the threats for which forces must prepare, as well as the corresponding capabilities and modes of action to be employed. Apart from the POKER training exercises conducted by the Strategic Air Forces (Forces aériennes stratégiques; FAS), simulated engagements are typically initiated at the unit level, with no nationally standardized or institutionalized lessons-learned framework. Despite proactive efforts and cooperation with Synapse Défense, training for defense against high-end GBAD threats remains in its early stages and continues to face several limitations:

- It is primarily conducted in simulators, which, regardless of their sophistication, introduce inherent biases, especially because of limitations in the realism and diversity of threat libraries available on current French simulation platforms.
- Live training is significantly constrained by the limited number and geographical deployment of ARPEGE threat emulators,[336] which can replicate certain enemy GBAD systems in training.
- It still involves a substantial amount of negative training because of the lack of realistic emulation of potential adversaries' operational doctrines beyond the mere technical replication of their weapons systems.[337]

Furthermore, the resilience of fighter aircraft to enemy electronic warfare remains relatively untested and undeveloped. French fighter crews, which routinely develop their tactics around extensive use of radar and communications systems, are not well accustomed to operating under EMCON conditions save for a few specific scenarios. Certain training

332. F. Giletti, *Rapport pour avis fait au nom de la commission de la défense nationale et des forces armées sur le projet de loi de finances pour 2024*, No. 1680, Assemblée nationale, October 26, 2023, available at: www.assemblee-nationale.fr.

333. Research interview with a retired general officer of the French Air and Space Force.

334. Research interview with a general officer of the French Air and Space Force.

335. L. Lagneau, "La première promotion 'QWI Rafale' a été diplômée par le Centre d'expertise aérienne militaire", *Zone militaire*, August 6, 2022, available at: www.opex360.com.

336. Research interviews with senior officers of the French Air and Space Force.

337. Research interviews with senior officers of the French Air and Space Force.

assumptions in this area are considered "brittle",[338] particularly regarding the electromagnetic transparency of the aerial battlespace and the growing optronic and collaborative electronic warfare capabilities of potential adversaries. The expertise developed during the 1980s and the Cold War in this domain needs to be updated: "At present, French doctrine is unable to break free from its dependence on emitting within the electromagnetic spectrum".[339] Lastly, France's ability to operate effectively in a Joint Engagement Zone (JEZ)—that is, in close tactical coordination between fighters, drones, and GBAD systems—remains limited, largely because joint training is infrequent,[340] despite the formal integration of the French Air and Space Force's GBAD units within the Fighter Aviation Brigade (Brigade aérienne de l'aviation de chasse).

## Command and control

In France, command and control of the air battlefield remains centralized, which is consistent with NATO air operations doctrine.[341] The concepts of mission command and distributed command have entered the operational lexicon and are being explored through the French Agile Combat Employment (ACE) initiative,[342] which envisions the deployment of French fighters to NATO bases during wartime. However, in addition to logistical constraints and base protection requirements, two major obstacles hinder their practical implementation.

On the one hand, implementation of these concepts directly conflicts with France's deeply ingrained culture of centralized air command. French military leadership has grown accustomed to real-time operational oversight—enabled by the widespread availability of communications systems and direct video feeds—and to the blurring of the operational and tactical levels, with rules of engagement set at the highest echelons and near-instantaneous reporting during operations in Africa and the Levant.

On the other hand, the air forces lack dedicated deployable C2 assets aside from the Expeditionary Command and Control Air Force Wing (Escadre aérienne de commandement et de conduite projetable), which is a centralized theater-level command structure, not a distributed system. French air units at the appropriate level for mission-type command—to be determined, but probably at the wing level—are neither equipped with such resources nor staffed with personnel trained in their operation.

338. Research interviews with senior officers of the French Air and Space Force.
339. Research interview with a retired general officer and senior officers of the French Air and Space Force.
340. Research interviews with senior officers of the French Air and Space Force.
341. P. Gros, "La décentralisation du commandement et du contrôle (C2) des opérations aériennes", *Recherches & Documents*, No. 12/2020, FRS, September 2020, available at: www.frstrategie.org.
342. "Czech and French Air Forces Conduct Agile Combat Employment Training", Allied Air Command Public Affairs Office, December 11, 2024, available at: https://ac.nato.int.

In conclusion, as of 2024, the French Armed Forces possess a clear human advantage and several technological strengths over their potential adversaries, including in air-to-air combat and low-altitude penetration. However, they lack the mass and organic depth required to sustain a high-intensity air campaign independently. The financial viability of transitioning to the next generation of equipment in sufficient quantity remains uncertain, especially given France's technological lag in critical areas such as stealth and SEAD. Moreover, the already fragile financial equilibrium of the French defense industry is faced with a historic convergence of two long-term trends amid a period of global instability. The first is the unchecked rise in the cost of acquiring and maintaining weapons systems and their associated munitions, which presents a structural risk over the next two decades.[343] The second is the mounting pressure on French public finances, which is raising concerns about the state's ability to absorb the "Augustinian" cost inflation associated with future defense programs.

# Recommendations

In an effort to partially address these shortfalls, the following paragraphs propose a series of recommendations aimed at restoring credible air superiority for the French Armed Forces. These recommendations are intended as avenues for reflection, mainly in terms of capabilities and organization. Their technical feasibility has been discussed with specialists. They are presented across two time horizons: short-term and medium-term. Within each mission area, the recommendations are ordered according to budgetary realism, starting with those least likely to cause crowding-out effects and ending with the most disruptive.

## *Short-term proposals*

The first time scale is the urgency underlined by Minister of the Armed Forces Sébastien Lecornu in his speech to the Directorate General of Armament (DGA) on October 24, 2024: "We lack the time to meet the challenges of a world that is rearming itself".[344] These short-term recommendations are guided by three core principles: addressing critical capability gaps, restoring a scalable inventory of platforms and munitions at a sustainable cost for public finances, and shifting from a platform-centric model to one centered on distributed sensors and effectors.

343. N. Augustine, *Augustine's Laws*, American Institute of Aeronautics and Astronautics, 1997.
344. Statement by Sébastien Lecornu, Minister of the Armed Forces, on the transformation of the Directorate General of Armament, in Vert-le-Petit on October 24, 2024, available at: www.vie-publique.fr.

## Format and coherence of fighter aviation

This first set of recommendations aims to realign French fighter aviation with current threats, while accounting for the potential postponement of the fifth Rafale tranche.

- Draft and validate a concept of operations for French combat aviation, specifying the tactical expectations for unit training.
- Accelerate the virtualization of air combat training through the LVCT program, standardize and harden training scenarios to match modern threat levels, and ensure they are regularly updated. Prioritize mission equipment (e.g., AESA antennas, pylons) and munitions in the implementation of the 2024–2030 LPM.
- Generalize the operational use of terrain-following flight modes on single-seat Rafales for all pilots qualified for wartime missions, with risk management aligned to the operational demands of high-intensity conflict.
- Equip the Rafale F4 with a towed decoy and/or self-propelled expendable decoys to enhance survivability.
- Integrate MICA firing in Mode III on the Rafale to allow for visual acquisition-based engagements guided by the helmet-mounted sight in close combat scenarios.
- Revise the Mirage 2000D modernization program to match the multirole Mirage 2000I standard already developed by Dassault Aviation for India; extend the airframe service life to 9,000 flight hours, as done for the Mirage 2000-5F; and proactively address supply chain issues to avoid an explosion in maintenance costs by 2035.

## SEAD

These recommendations aim to establish an initial SEAD capability before the end of the decade, in order to preserve national freedom of action in contested environments ahead of 2035.

- Rapidly develop—or procure off-the-shelf—a simple powered decoy comparable to the ADM-160 MALD and prioritize integration on Mirage 2000s, A400Ms (via internal bay launch), or even ground-based platforms.
- Procure an off-the-shelf batch of AGM-88 HARMs of any variant and integrate them onto the Rafale to quickly field a basic SEAD capability and begin developing the associated tactics, techniques, and procedures.

## OCA strike

This short set of recommendations is intended to strengthen the credibility of French OCA capabilities by building up a relevant munitions stockpile and providing the armed forces with the means to saturate opposing IADS.

- Develop the ability to launch cruise missiles and OWA drones from A400M bays, following the model of the American Rapid Dragon program, on the condition that a sufficient stockpile of munitions is available.[345]
- Prioritize aerial munitions procurement in the 2024–2030 LPM to ensure sustainability over the course of a high-intensity conflict. Identify and suspend specific regulatory standards that generate excessive production costs.
- Develop a family of OWA drones with performance characteristics similar to the Shahed-136. Acquire them in sufficient numbers to enable multiple salvos of 500 drones, aiming for a total inventory of 2,500 to 3,000 units, with a capacity for rapid mass production at the onset of a potential high-intensity conflict.

## DCA

In the defensive domain, the immediate priority is to rapidly develop capabilities to counter enemy saturating salvos, with cost-effectiveness being the main consideration.

- Develop or procure off-the-shelf a standardized 30-mm radar-guided AAA system for use across all three services, and deploy it at scale.
- Continue testing HELMA-P laser counter-drone weapons systems and extend their deployment across the three branches of the armed forces.
- To counter OWA drones, develop low-cost air-to-air missiles (targeting a price point around €50,000), using either Mistral MANPADS or 70-mm rockets, similar to the APKWS.[346]
- Develop drone swarm counter-drone systems, modeled on concepts such as Thales' RapidEagle[347] or MBDA's ALADIN.
- Upgrade the air-to-air gun aiming software on Rafale and Mirage 2000D aircraft to improve hit probability against small airborne targets.
- Modify the VL MICA for compatibility with the vertical launch systems (VLS) of French Navy surface vessels, to increase onboard missile capacity.

345. "Rapid Dragon Fact Sheet", Air Force Research Laboratory, March 28, 2023, available at: https://afresearchlab.com.
346. "APKWS® Laser-guidance Kit", BAE Systems, available at: www.baesystems.com.
347. "RapidEagle, le drone intercepteur de drone", Agence de l'Innovation de Défense, June 20, 2024, available at: www.defense.gouv.fr.

- For the French Navy, adapt the STRALES system to employ the Italian DART guided ammunition on 76-mm gun turrets.[348]

### Passive defense

In this area, where Cold War-era expertise must be relearned, the priority is to improve the ground survivability of the most expensive and scarce assets.

- Train operational personnel to conduct dispersal operations inside the perimeter of their home bases. Assess the human resource, maintenance, and towing equipment requirements needed to sustain such operations continuously in the event of conflict.
- Develop and procure inflatable or low-cost decoys replicating key equipment in service (e.g., Rafale, Mirage 2000D, SAMP/T, VL MICA) and train air unit personnel in their tactical use.

### C2

Finally, in the domain of C2, the following recommendations are intended to implement the distributed C2 concepts currently being developed within the armed forces.

- Develop a command framework for distributed operations within France's Air Defense and Air Operations Command (Commandement de la Défense Aérienne et des Opérations Aériennes; CDAOA), delegating authority down to the wing level, and equip these units with secure, deployable communications systems.
- Expand the French ACE concept to include the regular deployment of combat aircraft—and, critically, their operational and logistical support, including munitions—to a select network of civilian airfields in France, to facilitate dispersal.
- Make substantial investments in AI and develop dedicated applications to enhance air warfare operations, with four priorities: mission planning and tasking, autonomy for unmanned air systems, targeting processes, and aircrew training.

## Proposals for 2035

- The long-term recommendations focus primarily on capability development and major weapons programs beyond a decade-plus timeline. The objective is to establish a combat aviation that clearly distinguishes between stand-in and standoff capabilities. Achieving mass through the use of drones, combined with a limited number of high-value decisive weapons, should enable the armed forces to saturate and break

348. "The Strales 76mm System with DART Guided Ammunition", Leonardo, April 18, 2014, available at: www.leonardo.com.

through adversary defenses and secure lasting air superiority from the opening hours of a conflict.

- Develop a family of modular air-to-ground saturation munitions configurable for OCA missions, including SEAD, where individual performance is secondary to low unit cost and mass-production potential, following the model of Anduril's Barracuda-M program.[349]
- Develop an external offensive jamming pod adaptable to a wide range of platforms, including the Rafale, the A330 MRTT, the Archange, the E-3F AWACS successor, and the A400M.
- In parallel with modernization of the Meteor MLA, develop a dedicated SEAD or dual air-to-air and SEAD variant of the Meteor, equipped with a modified warhead and dual-mode seeker combining active/passive X-band and millimeter-wave radar.
- Develop or procure off-the-shelf an aeroballistic MaRV-type munition to target the most advanced SAM systems, similar to variants derived from the Israeli Blue Sparrow ballistic target.[350]
- Develop a low-cost UCAV—priced around €5 million per unit excluding payload—to be prioritized over the current Rafale F5 escort UCAV program, with potential commonality of the onboard AI, and pursue mass deployment with a target of at least 200 units.
- Disperse GBAD assets to increase unpredictability and surprise potential, by integrating remote launchers into unmarked land or sea-based platforms, such as standard 20-foot containers.
- Rethink the role of the NGF within a tandem framework alongside the Rafale F5, rather than as a stand-alone multirole platform, by prioritizing its design for entry force missions in complement to the Rafale F5. In this reverse high-low mix, similar to the USAF's F-15EX/F-35A pairing, the NGF and its associated drones (see above) would focus on escort and SEAD missions, while the Rafale formations would carry the majority of the overall firepower.

349. "Anduril Unveils Barracuda-M Family of Cruise Missiles", Anduril, September 12, 2024, available at: www.anduril.com.
350. "ROCKS[tm] Autonomous Extended Stand-Off Range Air-to-Surface Missile", brochure, Rafael, 2024, available at: www.rafael.co.il.

# Conclusion

Until the 2010s, Western air superiority doctrine rightly prioritized an offensive posture focused on destroying enemy air forces on the ground and neutralizing the adversary's IADS. As the 2030s approach, however, this posture is no longer sufficient. Western air power now faces potential adversaries that have developed a wide array of means to bypass or degrade traditional air power.

These potential adversaries are advancing at different paces: Russia is progressing more slowly and remains hindered by persistent human and doctrinal shortcomings, while China is advancing far more rapidly. The Russian air force does not yet pose an existential threat to NATO's air power, but its long-range strike capabilities put critical European rear-area air infrastructure at risk—assets that are essential to controlling the skies. Meanwhile, the Russian and Chinese IADS and those of their client states continue to grow in strength and density. These are the primary obstacles to Western air superiority.

Air combat over the next decade will continue to be shaped by radar stealth and the ability to suppress or degrade the enemy IADS through SEAD and precision air strikes. These missions must evolve from a model based on individual platform excellence to one centered on saturation and long-term economic viability. Western offensive doctrine thus remains relevant, but only if it is supported by a stronger defensive posture, particularly at the lower end of the technological spectrum. In this regard, AAA will be essential for protecting rear areas against saturation attacks by drones or pre-programmed munitions. In both offensive and defensive approaches, technological superiority in sensors will remain a cornerstone of air superiority.

At present, France is not prepared to sustain a prolonged fight for air superiority, though it remains capable of winning local air combat, and of sneaking through a modern IADS and conducting limited conventional or nuclear strikes. To enable France to bear its share of responsibility in a high-intensity coalition conflict or to prevail in a war against a near-peer adversary, this study proposes five main categories of recommendations:

- Prioritize the equipment and modernization of existing combat aircraft.
- Shift from a platform-centric approach to one focused on distributed sensors and effectors.
- Emphasize munition quantity and collaborative targeting over individual penetration capability.

- Break free from the Augustinian cost spiral associated with fighter aircraft by investing in stealth only where operationally essential and build a differentiated force structure balancing stand-in and standoff capabilities.
- Develop CCA/RC and GBAD systems with the aim of regaining mass rather than optimizing each system's individual performance.

Alongside these efforts, a joint study and educational initiative on air superiority appears essential in France, as the subject—admittedly technical in nature—remains poorly understood by many political and military decision-makers. A concerted effort of this type would serve to unify expertise and intent, ensuring—should France face a high-intensity conflict in the coming years amid a rapidly shifting global order—that national efforts would first and foremost be directed toward achieving control of the air as the prerequisite for success in all other domains.

# Appendix - List of acronyms

| | |
|---|---|
| A2/AD | Anti-access/area denial |
| AAE | French Air and Space Force |
| AASF | Future air-to-ground weapon |
| AASM | Modular air-to-ground weapon |
| ACO | Airspace control order |
| AESA | Active electronically scanned array |
| AEW | Airborne early warning |
| AI | Artificial intelligence |
| ATACMS | Army Tactical Missile System |
| ATO | Air tasking order |
| AWACS | Airborne Warning and Control System |
| C2 | Command and control |
| CAP | Combat air patrol |
| CCA | Collaborative Combat Aircraft |
| CEMA | Chief of the French Defense Staff |
| CNA | Airborne nuclear component |
| COMAO | Composite air operation |
| DCA | Defensive counter air |
| DEAD | Destruction of enemy air defenses |
| DRFM | Digital radio frequency memory |
| ELINT | Electronic intelligence |
| EMCON | Emission control |
| ESM | Electronic support measures |
| F2T2EA | Find, Fix, Track, Target, Engage, Assess |
| FAS | Strategic Air Forces |
| FCAS | Future Combat Air System |
| FDI | Defense and intervention frigate |
| FMAN | Future anti-ship missile |

| | |
|---|---|
| FMC | Future cruise missile |
| FREMM | European multi-purpose frigate |
| GBAD | Ground-based air defense |
| HALE | High-altitude long-endurance |
| HARM | High-speed anti-radiation missile |
| HVAA | High-value airborne asset |
| IADS | Integrated air defense system |
| IRST(S) | Infrared search and track (system) |
| JADC2 | Joint All-Domain Command and Control |
| LAD | Counter-UAS warfare |
| LO | Low observable |
| MADL | Multifunction Advanced Data Link |
| MALD | Miniature Air-Launched Decoy |
| MALE | Medium-altitude long-endurance |
| MANPADS | Man-portable air defense system |
| MaRV | Maneuverable reentry vehicle |
| MRBM | Medium-range ballistic missile |
| NGAD | Next Generation Air Dominance |
| NGF | New Generation Fighter |
| NGWS | Next Generation Weapon System |
| OCA | Offensive counter air |
| OODA | Observe - orient - decide - act |
| OTH | Over the horizon |
| OWA | One-way attack |
| PET | Preemptive targeting |
| Pk | Probability of kill |
| PLA | People’s Liberation Army |
| PLAAF | People’s Liberation Army Air Force |
| PPS-A | Permanent air security posture |
| RCS | Radar cross-section |
| SA | Situational awareness |
| SAM | Surface-to-air missile |
| SAMP/T | Surface-to-Air Missile Platform/Terrain |

| | |
|---|---|
| SAS | Special Air Service |
| SEAD | Suppression of enemy air defenses |
| SP | Self-protection |
| SRBM | Short-range ballistic missile |
| TALD | Tactical Air-Launched Decoy |
| TOO | Target of Opportunity |
| UCAV | Unmanned combat aerial vehicle |
| UHF | Ultra high frequency |
| VHF | Very high frequency |
| VLO | Very low observable |
| VKS | Воздушно-космические силы (Russian Aerospace Forces) |

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