

FlightPlan

A VOLUNTEER NEWSLETTER BY VOLUNTEERS



Radar Absorbing Materials

Page 12

Bin Laden Raid Stealth Black Hawks

Page 22

F-117A Reunion

Page 28

**EVERGREEN
AVIATION & SPACE
MUSEUM**



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BILL KOLB

FLIGHTPLAN EDITOR, MONDAY DOCENT

Welcome to the April edition of the FlightPlan newsletter. This month focuses on stealth. Here at the Museum, we are lucky to showcase some of the most iconic examples of military aircraft cloaked in stealth technology, including the SR-71 Blackbird, F-117A Nighthawk, and the D-21B stealth drone. This edition begins with an article that traces the history of stealth through the ages. Like a Michener novel, we start 400,000 years ago in the Paleolithic Era, when early humans used animal hides to conceal themselves while hunting. The article covers camouflage techniques across land, sea, and air platforms throughout history. Deeper into the document, the articles fall into two main categories: 1) Stealth related to a specific aircraft, and 2) A discussion of the design, manufacture, and application aspects of a particular stealth technology.

We hope you enjoy our monthly offering. ➤

MONTHLY THEMES

We are assigning themes to each month of the FlightPlan. These are not exclusive of other topics, but perhaps they may motivate you to make a contribution.

APRIL.....STEALTH

JUNE.....THE EARLY DAYS OF SPACE
EXPLORATION

MAY.....THE EARLY DAYS OF AVIATION

GUIDELINES FOR SUBMITTING ARTICLES TO FLIGHTPLAN

1. The FlightPlan (FP) is published on the 1st of each month
2. Stories for the next issue can be filed up to the 10th of the prior month
3. Articles should be associated with an artifact at the Museum
4. Sources for specific information in the article should be provided
5. Stories should be approximately 500 words long
6. If appropriate, include one or two photos for publication with the article
7. Include name, day, and title at the bottom of each article submitted
8. Email articles to: **flightplan@evergreenmuseum.org**
9. Feedback is encouraged; submit to **flightplan@evergreenmuseum.org**

CAPTAINS CORNER

JERRY SAUTER

TUESDAY DAY CAPTAIN

March 2026 BOC meeting. Topics are presented below; to avoid a multi-page report, anyone with further questions regarding the discussions can contact their Day Captain.

Scot Laney – Chief Executive Officer

- Expressed his goal to make our Museum the best air and space museum with the help and cooperation of all volunteers and staff.
- A series of organization and exhibit changes are planned for April. Details will be forthcoming.
- Introduced Robby Worley as the new Restoration Manager. Robby is a retired Air Force veteran. He is scheduled to be in the Museum Monday through Friday from 9am to 1pm.
- The restoration of the floor in the old Kids Zone in the Hercules building is nearly complete and will be available for the Band of Brothers meeting on March 6.

Terry Howell – Chief Operating Officer

- The Carlton Observatory will hold a Science Fair on Saturday, March 7 in the Titan Pavilion. Attendees will be able to tour the Hercules Pavilion for \$5.
- The McMinnville Wine and Food Festival (aka The SIP) will take place on March 13, 14, and 15 and will be set up in both museum pavilions.
- Many activities are planned for this year's Spring Break. Among them are an open-cockpit seating of the F-4 Phantom. This will be offered to museum members only for this specific event.
- A new "Cockpit Club" membership program will be launched after Spring Break.
- The Volunteer Appreciation dinner will be held on March 19. The starting hour was changed from 6:30pm to 5:30pm to accommodate those who prefer not to drive in the dark.
- There will be a Museum fund-raising event, "Throttles and Bottles," on April 25. Details to follow.

Scott Malandrone – Exhibits Manager

- A pathway beneath the Wright Flyer has been opened. Visitors may now walk under the aircraft for a better view.

Old Business:

- Volunteer Handbook: Dan Oven reported that a proposed final version will be available for Day Captains' and Leads' review at the April BOC meeting.
- Outreach support: Visiting or providing another type of support to the Veterans Home in Sweet Home was discussed.

New Business:

- Shutdown and start-up procedures for new general information monitors in the Hercules Pavilion were

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CAPTAINS CORNER

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discussed. Similar monitors are planned for the Titan Pavilion.

- Emergency notification process: A discussion of how to handle unusual or threatening situations took place.

The meeting was adjourned at 11:22 am. ✈



FROM THE CEO

Stealth: Difficult to Achieve, Difficult to See

SCOT LANEY

MUSEUM CEO



The History of Stealth in Military Applications

Tracing Back Our Prehistoric and Ancient Roots of Stealth and Camouflage

BILL KOLB

MONDAY DOCENT

The origins of stealth and camouflage predate recorded history, rooted in the survival instincts of early humans. As far back as the Paleolithic era, approximately 400,000 years ago, hominids used animal hides not only for clothing but also for concealment during hunting. Archaeological evidence, including tools for scraping and processing skins, suggests that early humans, such as Neanderthals, fashioned rudimentary capes from fur-bearing animals such as wolves and Arctic foxes to blend into their environments and approach prey undetected. These hides provided thermal protection while allowing hunters to mimic the appearance and scent of local fauna, reducing the chance of startling game. Cave paintings provide vivid glimpses into these practices: a 30,000 BC artwork from the Trois-Frères cave in France



depicts a human figure adorned with an animal head, tail, and likely a full skin, a technique used by hunters to mimic animals and close in on herds without alarming them. This “sorcerer” figure highlights how camou-

flage was intertwined with ritual and strategy, possibly invoking spiritual aid for successful hunts.

Similarly, red ochre drawings in the Shakhty Caves of Central Asia, dating to around 8,000 BC, depict hunters cloaked in animal skins as they pursue wild oxen with bows and arrows, illustrating camouflage’s dual role in practical hunting and possibly in ceremonial rituals. As agriculture emerged around 10,000 BC, these methods adapted, with early farmers using woven grass mats or mud-smearred bodies to hide from predators or rival

groups raiding crops. In the Neolithic period, evidence from sites like Çatalhöyük in Turkey suggests that communities painted dwellings with natural pigments to blend into the landscape, deterring invaders.

As human societies evolved into organized tribes and empires, these techniques transitioned from hunting to warfare. Ancient civilizations employed natural materials like mud, leaves, tree bark, and animal hides to conceal warriors and gain tactical advantages. In ancient Greece, hunters and soldiers used grass-and-leaf headpieces to blend into open fields during ambushes, as described in Homeric epics, where heroes like Odysseus employed disguises for reconnaissance. Historical records indicate that Roman soldiers dyed their cloaks in colors that mimicked the terrain for stealthy maneuvers, with legions in forested Gaul using bark armor to blend into trees. One of the

earliest documented examples of organized military deception is the Trojan Horse, around 1184 BC, in which Greek forces hid inside a wooden structure disguised as a gift to infiltrate Troy, blending outright subterfuge with camouflage principles. This ploy, immortalized in Virgil’s Aeneid, demonstrated how large-scale illusions could turn the tide of sieges.



Naval stealth also developed early: during the Gallic Wars (56–54 BC), Julius Caesar’s scout ships were painted in “Venetian blue,” a bluish-green color resembling the

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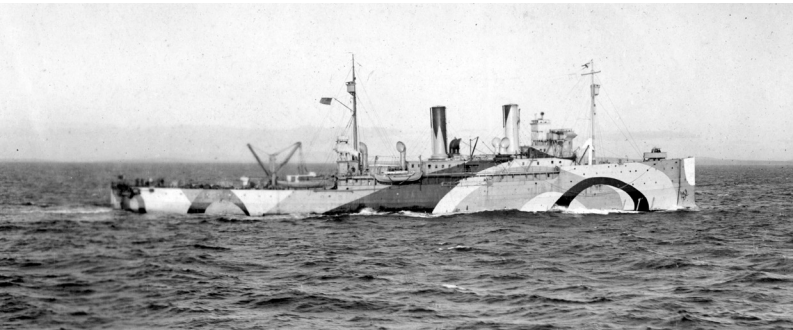
The History of Stealth in Military Applications

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sea, to avoid detection along Britain's coast, as noted by the Roman writer Vegetius. Egyptian pharaohs around 1500 BC used reed boats camouflaged with papyrus to ambush river enemies, while Assyrian reliefs from 700 BC show archers hidden behind woven shields that imitate rocks. These ancient techniques laid the foundation for systematic stealth, emphasizing blending with the environment to surprise in battle, and influenced later strategies in Sun Tzu's *Art of War*, which promoted deception as the core of strategy.

Origins of Modern Stealth Technology

Fast forward to the early 20th century. Modern stealth technology, which aims to reduce detectability through radar, infrared, visual, and acoustic means, has roots tracing back to ancient warfare but gained significant traction during World Wars I and II.



Early efforts focused on visual camouflage, such as painting ships with disruptive patterns to confuse range-finding optics. By World War II, the advent of radar prompted innovations in radar-absorbing materials (RAM). German engineers applied ferrite-based coatings to U-boat snorkels and periscopes to evade Allied radar, while the U.S. developed similar materials for aircraft and ships. Chaff—strips of aluminum foil—was deployed to create false radar echoes, effectively jamming enemy systems. The German Horten Ho 229 flying wing, with its wooden construction and minimal metal, inadvertently reduced radar cross-section (RCS), marking an early, unintended step toward stealth aircraft.

Post-war, the Cold War escalated stealth research, with the U.S. CIA funding projects to minimize the RCS of spy planes like the U-2. In 1956, attempts to reduce the U-2's RCS included wires, ferrite beads, and radar-absorbent paint, though results were mixed due to weight and drag penalties. Soviet physicist Pyotr Ufimtsev's 1962 paper on electromagnetic wave diffraction became foundational; it was translated by the U.S. Air Force, enabling computer modeling for RCS reduction. DARPA's "Have Blue" program in the 1970s marked the shift to integrated stealth designs, blending shape, materials, and electronic countermeasures. This era saw stealth evolve from mere camouflage to a multidisciplinary approach, incorporating advanced composites and propulsion to evade increasingly sophisticated threats.

Stealth in Buildings

While stealth is often associated with mobile platforms, its principles have also been applied to fixed structures such as factories, bunkers, and command centers to protect against aerial reconnaissance and bombing. During World War II, the U.S. employed elaborate visual camouflage for aircraft plants. One such case was the Lockheed Burbank facility, under "Operation Camouflage," led by Colonel John F. Ohmer. See a detailed telling of the Lockheed story in the companion article, *Camouflaging the Lockheed Burbank Aircraft Plant*.

Modern applications include radar-absorbent coatings on buildings housing sensitive equipment, like radar sites or missile silos, to reduce RCS. For instance, integrated air defense structures use angled designs and RAM to deflect radar waves. In the 1980s, stealth principles influenced the design of hardened bunkers, incorporating low-observable materials to evade satellite and drone surveillance. Today, urban military installations blend into civilian architecture, with metamaterials minimizing infrared signatures from heat-emitting buildings. Facilities like Area 51 employ multi-spectral camouflage, combining visual deception with electronic countermeasures

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The History of Stealth in Military Applications

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to obscure operations. These techniques extend WWII innovations, adapting to threats like hypersonic missiles and AI-driven reconnaissance.

Stealth in Ships

Naval stealth evolved from WWII camouflage paints on warships to advanced RCS reduction for surface vessels. Early efforts included Germany's layered resistive sheets on submarines to absorb radar waves. Post-war, the U.S. Navy explored stealth with the Sea Shadow (IX-529),



an experimental 1980s vessel built by Lockheed with a faceted hull and tumblehome design to deflect radar, tested secretly until 1993. You can find a full article about this unique experiment under the title The Lockheed Sea Shadow.

Other examples include Norway's Skjold-class corvettes and France's La Fayette-class frigates, the first ocean-going stealth ships in the 1990s, using sloped superstructures and quiet propulsion to minimize sonar and infrared signatures. Stealth ships enable undetected approaches for strikes or reconnaissance, shifting naval warfare toward low-observable fleets.

Although the Sea Shadow never participated in combat, its impact persists. Technologies developed for the project have shaped modern naval design, including streamlined radar profiles on submarine periscopes and

the U.S. Navy's Zumwalt-class destroyers. Additionally, it has influenced pop culture, including the stealth ship featured in the 1997 James Bond movie *Tomorrow Never Dies*.

Stealth in Submarines

Stealth in submarines focuses primarily on reducing acoustic signature to evade sonar and minimizing magnetic and radar signatures when near the surface. Germany led early efforts in World War II: the experimental U-480 became the first true stealth submarine, coated in Alberich anechoic rubber tiles containing air pockets that absorbed sonar pings. Radar-absorbent materials were applied to snorkel heads, reducing radar returns by up to 90% and allowing safer submerged diesel operation. After the war, nuclear propulsion in the USS Nautilus (1954) enabled indefinite submerged endurance, removing the need to surface frequently.

Cold War competition produced quieter designs through sound-isolating machinery rafts, advanced propellers, and hull coatings. Today's U.S. Seawolf-class submarines achieve acoustic signatures quieter than ambient ocean noise (below 90 decibels) using powerful S6W nuclear reactors and pump-jet propulsors. The Virginia-class builds on this with anechoic tiles, rafted equipment, and pump-jets that eliminate cavitation, making them quieter than Russia's formidable Akula-class and capable of undetected patrols for nuclear deterrence and intelligence gathering. However, challenges persist, as Virginia-class subs have experienced peeling stealth coatings, potentially increasing their detectability. Future SSN(X) programs aim to combine Virginia's stealth with Seawolf's firepower, incorporating AI for adaptive noise reduction.

Stealth in Aircraft

Aviation stealth revolutionized air power, starting with the Lockheed SR-71 Blackbird in 1966. This Mach 3+ reconnaissance jet used titanium construction, radar-ab-

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The History of Stealth in Military Applications

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sorbing iron ferrite paints, and angled edges to lower its RCS, relying primarily on extreme speed and altitude for evasion and surviving over 1,000 surface-to-air missile attempts throughout its career until retirement in 1998.

The Lockheed F-117A Nighthawk, operational from 1983, was the first aircraft designed entirely around stealth principles. Its faceted, angular “diamond” shape deflected radar waves, achieving an RCS comparable to that of a small bird, while internal weapons bays, radar-absorbent materials, and the absence of afterburners minimized infrared and visual signatures. It flew subsonically at night and proved decisive in the 1991 Gulf War for precision strikes in heavily defended airspace. Please turn to the article, The F-117A Nighthawk, for a longer recitation of the aircraft’s myriad stealth technologies.

Later, in 1999, an F-117A was lost over Serbia due to tactical factors rather than a design failure. See a detailed account of Serbia’s downing of our F-117A in the article, Back in Black.

The Lockheed Martin F-22 Raptor, entering service in 2005, represents fifth-generation integration: curved surfaces and precise edge alignment maintain low RCS while preserving supercruise (sustained supersonic flight without afterburners), thrust-vectoring agility,



and sensor fusion for “first-look, first-kill” superiority. Internal bays and sophisticated coatings complete its low-observable profile. Beyond these icons, the B-2 Spirit bomber and modern unmanned systems continue the evolution. Globally, China’s J-20 and Russia’s Su-57 reflect the proliferation of stealth technology, though countermeasures like low-frequency radar challenge its dominance.

Stealth has transformed warfare, emphasizing information dominance and survivability, but its future lies in adaptive, multi-domain systems to counter evolving threats.

What follows in this edition are smaller individual articles about stealth applications. Some are mentioned above, but there are many more included for your reading pleasure.

Enjoy! ✈



Stealth Aircraft Design Principles

The 90% Radar Visibility Reduction Before Radar Absorbing Materials Are Applied

BILL KOLB

MONDAY DOCENT

Stealth technology, also known as low-observability (LO), aims to reduce an aircraft's detectability across various spectra, with its main goal being to lower radar cross-section (RCS). By decreasing RCS from typical fighter levels of 5–25 m² to 0.001 m² or less from the front, stealth aircraft can appear as small as a bird or insect on enemy radar, significantly shortening detection range.

The foundation of modern stealth lies in aircraft design and geometry. Shaping accounts for the vast majority of RCS reduction—often over 90%—by physically redirecting radar waves away from the source rather than absorbing or scattering them diffusely.

Shaping and Geometry: The Dominant Factor in Stealth Design

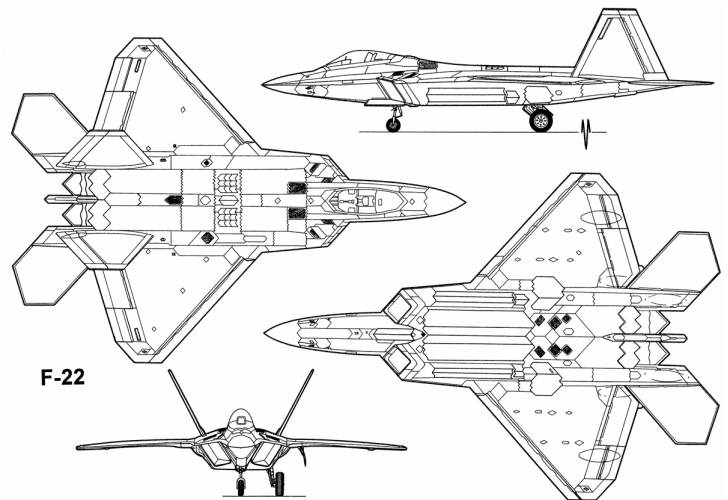
Radar waves reflect specularly, much like light on a mirror. Stealth aircraft are therefore engineered so that incident waves strike surfaces at oblique angles and bounce away from likely threat radars, creating large “cones of silence” in critical forward sectors.



The most effective technique is planform alignment. Designers align the leading and trailing edges of wings, tails, canards, and other main surfaces to just a few sweep angles. This focuses returns into narrow spikes instead of wide, noticeable scattering. Vertical stabiliz-

ers are tilted, and every panel, door, and hatch features serrated or saw-tooth edges that maintain these key angles.

Early operational designs like the F-117 Nighthawk depended on faceting—arrays of flat, angled panels. This method is directly derived from Soviet physicist Pyotr Ufimtsev's 1962 Physical Theory of Diffraction, which provided the mathematical tools for predicting and reducing edge scattering. Lockheed's Skunk Works used these equations on the “Hopeless Diamond” shape of the Have Blue demonstrator, which proved the concept before the F-117A went into production.



Modern aircraft transitioned to continuous curvature and blended surfaces enabled by supercomputing and advanced electromagnetic modeling. The F-22 Raptor and F-35 Lightning II feature smooth, organic contours that maintain low RCS while delivering superior aerodynamics and maneuverability. The ultimate expression is the pure flying-wing configuration of the B-2 Spirit and forthcoming B-21 Raider. Eliminating the fuselage and vertical tail removes entire classes of radar-reflective edges and corners, delivering exceptional all-aspect stealth.

Supporting geometric features are equally critical: serpentine (S-duct) engine inlets that hide highly reflective compressor blades from direct illumination; fully inter-

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Stealth Aircraft Design Principles

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search-and-track systems detect engine heat from long ranges. Stealth designs, therefore, incorporate extensive optical masking and plume suppression from the outset.

The dominant IR sources are hot turbine sections and exhaust plumes. Primary techniques include engine burial and optical blocking—engines are deeply recessed, and in the B-2, the flattened exhaust is routed over the upper wing surface through titanium “aft-deck” trenches, shielding hot gases from ground observers while mixing them with cool boundary-layer air. Non-circular nozzles, such as the F-117A’s “platypus” tail and the F-22’s rectangular exits, increase perimeter-to-area ratio for faster cooling and reduce the visible cross-section of hot parts. Serrated chevron nozzles on the F-35 generate vortices that rapidly mix hot-core flow with cooler bypass air, dramatically shortening and cooling the plume.

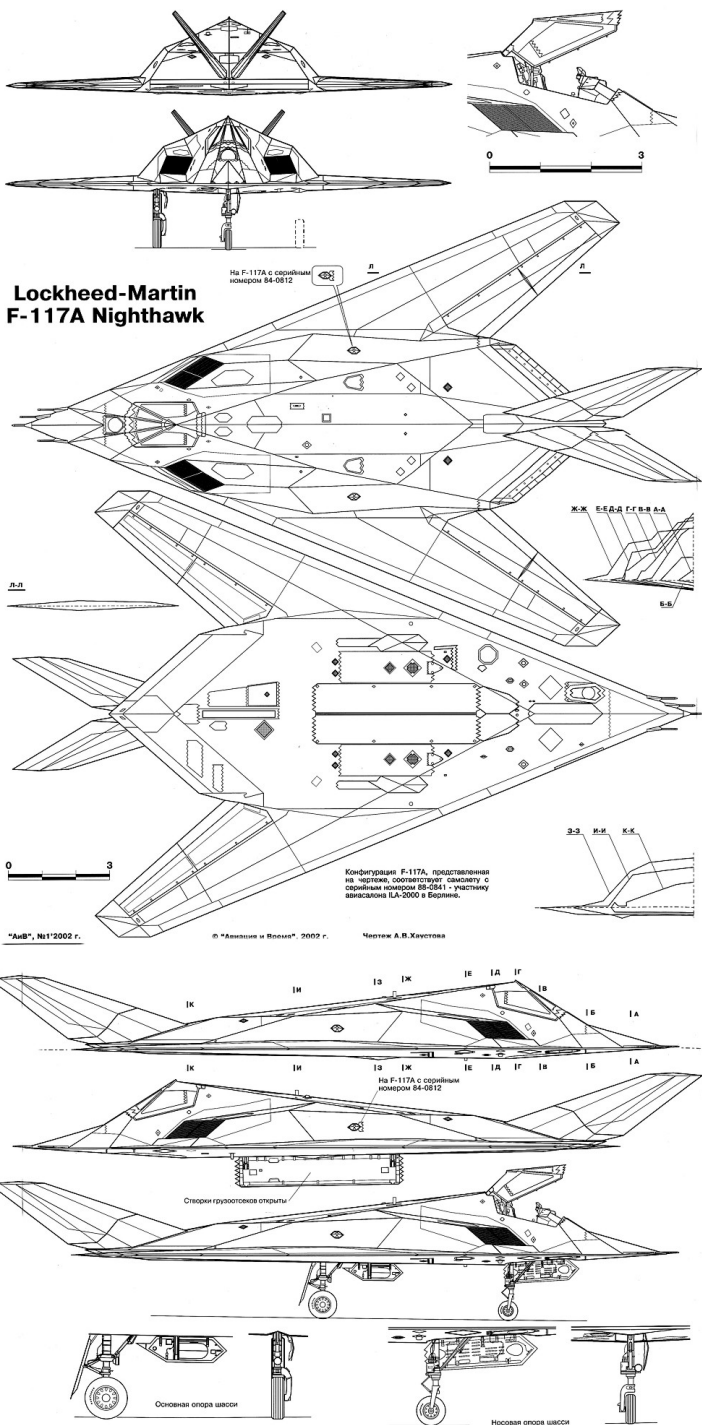
Additional measures include low-emissivity coatings on rear surfaces, cooled exhaust decks, and serpentine ducts that further obscure the line of sight to the turbines.

Trade-offs, Limitations, and Evolution

These geometric and thermal-control choices come with compromises: increased drag in certain regimes, reduced weapons volume, and extreme manufacturing precision requirements. Stealth shaping drives higher costs and demands specialized maintenance. Yet the payoff is survivability, allowing aircraft to penetrate defended airspace with far lower risk.

Stealth has evolved from the subsonic, night-only F-117 to agile, supercruising platforms. Future designs, such as the B-21, will refine these principles through adaptive structures and broader multi-spectral optimization to counter evolving threats, including low-frequency radars and advancedIRST systems.

In essence, modern stealth is fundamentally an exercise in sophisticated aircraft design—using geometry and configuration to control both radar and infrared signatures rather than relying on any single material solution.



Lockheed-Martin
F-117A Nighthawk

nal weapons bays that keep stores out of the airstream and away from radar; and precise gaps and seam control on every access panel to prevent diffraction.

Infrared Signature Reduction and Masking

Radar is not the only threat. Infrared (IR) seekers and

Radar Absorbing Materials

The Holy Grail of Stealth

BILL KOLB

MONDAY DOCENT

Introduction

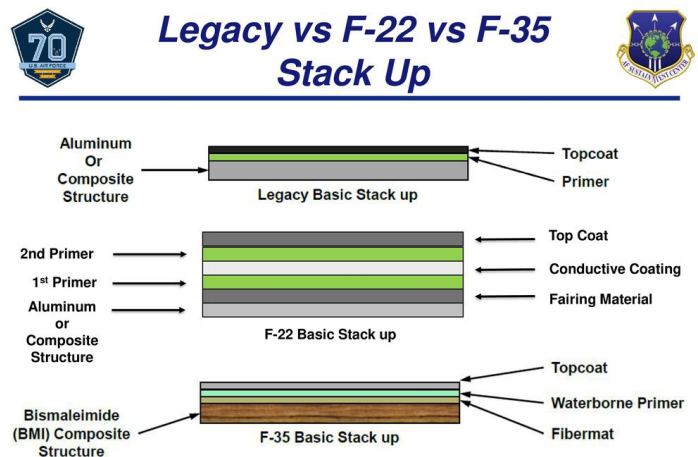
Radar Absorbing Material (RAM) is a key technology in military aircraft, helping them evade enemy radar by absorbing radio waves rather than reflecting them. It emerged during the Cold War, when radars improved at spotting aircraft, so engineers needed ways to make planes sneakier. RAM works alongside the plane's shape to turn those waves into heat, making the aircraft harder to detect across a range of radar signals. This has been crucial for planes like the SR-71 Blackbird, F-117A Night-hawk, and F-22 Raptor, where staying invisible is more important than just being fast or strong. In real battles, such as the Gulf War, these stealth features helped planes complete missions without getting shot down. But RAM isn't perfect—it can add weight and require regular maintenance to counter wear and tear, leading to new materials like tiny particle mixtures for better toughness. This article looks at how RAM works and how it's used in those famous U.S. planes.

The Physics of RAM

RAM is all about handling invisible radio waves from radar, which are like the signals your phone uses but tuned to spotting large objects in the sky. These waves carry energy in the form of electric and magnetic fields that oscillate back and forth, much like a wave on a string, but invisible and super-fast. When they hit a smooth metal surface, the surface acts like a mirror, reflecting the waves straight back to the radar station, which then picks up the echo and pinpoints the plane's location, speed, and even size.

RAM flips this script by acting like a sponge or a black hole for those waves, pulling them in and converting their energy into harmless heat that dissipates into the air. This reduces the echo to almost nothing, making the plane look tiny or invisible on radar screens. The key is the materials' ability to interact with the wave's electric and magnetic components without much of it bouncing back.

Let's break it down further. Dielectric RAM focuses on the electrical side: it often uses carbon particles mixed into polymers or plastics. When a wave hits, the carbon creates tiny electric currents that flow through the material. These currents encounter resistance, generating friction, like tires skidding on pavement, which converts the wave's energy into heat. Imagine the wave as a surfer: on metal, it rides back smoothly, but in dielectric RAM, it gets bogged down in a rough sea until it wipes out completely. Carbon is chosen because it's light-weight, inexpensive, and tunable; varying the amount of carbon allows engineers to target specific radar frequencies, from high-pitched ones used for precise tracking to lower ones for long-range detection.



On the magnetic side, RAM incorporates iron particles or ferrites—special alloys like barium or strontium compounds. These materials mess with the wave's magnetic field through a process called hysteresis, where the material's internal magnets lag behind the wave's changes, creating drag that saps energy. It's like pedaling a bike with sticky gears; the effort (wave energy) gets wasted as heat from the resistance. Ferrites are great for absorbing slower, longer waves that penetrate more deeply, thereby complementing dielectric materials for full coverage.

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Radar Absorbing Materials

The Holy Grail of Stealth

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Engineers don't stop at single layers; they build RAM like a multi-layer cake or sandwich to handle a broad spectrum of frequencies. A top layer might grab high-frequency waves, while deeper layers trap slower ones through multiple bounces. Pyramid or honeycomb shapes inside amplify this by creating internal mazes where waves ricochet until exhausted, similar to sound-proof foam in a recording studio that absorbs echoes. This "graded" design ensures broadband absorption, meaning it works against various radar types, not just one.

Newer innovations amp this up with nanomaterials like carbon nanotubes, which are rolled-up sheets of carbon atoms forming ultra-thin tubes. These provide a massive surface area for friction, enabling highly efficient absorption in thin, lightweight layers—perfect for not weighing down a plane. Some RAM even uses metamaterials, engineered structures that bend waves around the object like water around a rock, effectively cloaking it. But challenges remain: absorbed energy can overheat the coating, high speeds cause aerodynamic wear, and moisture from rain might degrade it. Solutions include adding ceramics for heat resistance or flexible polymers that self-repair cracks.

In essence, RAM turns physics against the radar—using friction, resistance, and clever layering to swallow signals whole. It's not foolproof against all detection methods, like infrared or visual spotting, but for radar dominance, it's a game-changer, requiring constant tweaks to stay ahead of evolving threats.

Specific Applications

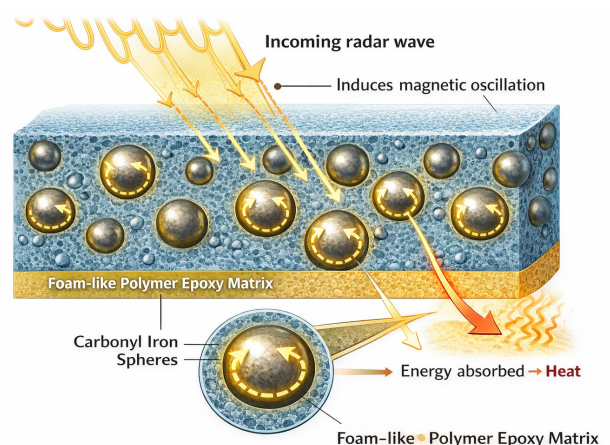
SR-71

The SR-71 Blackbird, in service from 1966 to 1998, used early RAM to achieve Mach 3+ speeds and reach 85,000 feet during spy missions. Its titanium body featured curved edges to scatter waves and was coated with iron ferrite paint in honeycomb structures. The honeycomb was made of asbestos-fiberglass over aluminum, chosen

for heat tolerance and insulation while adding minimal weight. "Iron ball" paint, with iron spheres in a black coating, created magnetic fields to dissipate heat and aid camouflage and thermal management. Silicone-asbestos laminates on sawtooth edges minimized reflections. Cesium in the exhaust formed absorbing plasma clouds, and jagged inlets hid the turbines. Though its echo resembled a small jet, it evaded over 1,000 missiles, highlighting RAM's role in high-speed ops.

F-117A

The F-117A Nighthawk, active from 1983 to 2008, pioneered stealth, using angular shapes to deflect waves and RAM to absorb remnants, reducing echo to bird-size. Iron ball paint with carbonyl iron in epoxy created magnetic losses for heat conversion and bonded durably to facets. Neoprene sheets with ferrite or carbon black offered flexibility and heat-dissipating conductivity. Linoleum-like sheets were adhered to the body for broadband coverage, with a caulking-like substance filling gaps. Carbon coatings reduced weight while boosting stealth. Engine covers and exhausts hid signatures. In the 1991 Gulf War, it completed 1,300 undetected missions. Maintenance was intensive due to weather-related wear.

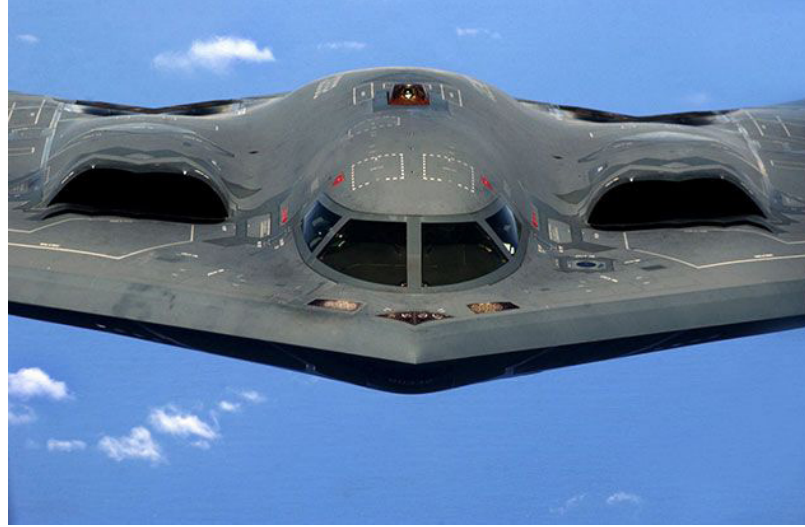


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Radar Absorbing Materials

The Holy Grail of Stealth

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F-22

The F-22 Raptor, from 2005 onward, advances stealth with curves and integrated RAM, minimizing echo to marble-size. Wide-band composites on wings absorb frequencies without peeling in maneuvers. Ceramic matrix on nozzles withstands supersonic heat while converting energy. Polymer coatings with nickel-zinc ferrites, applied as tiles, provide lightweight broadband protection. A boot layer under the topcoat offers self-healing durability. Baked into the skin for strength, it supports fast flights. Weapon doors and nozzles maintain clean, cool profiles. Updates include longer-lasting self-fixing layers. It blends stealth, agility, and sensors for superior combat.



Conclusion

From basic paints to high-tech mixes, RAM has changed how military planes hide and fight, using everyday physics ideas like friction and trapping to beat radars. It helped the SR-71 spy fast, let the F-117A strike unseen, and gives the F-22 total air control. Looking ahead, smarter materials that adjust on the fly could keep planes one step ahead of new threats. Staying innovative with RAM is vital for future air power. ➤



A scanning electron microscope (SEM) image showing a dense field of carbon nanotubes. The nanotubes appear as numerous small, cylindrical tubes, some oriented vertically and others horizontally, creating a complex, textured pattern. The background is dark, making the bright, metallic-looking tubes stand out.

What Are Carbon Nanotubes?

BILL KOLB

MONDAY DOCENT

Introduction

Carbon nanotubes (CNTs) are tiny, tube-like structures made entirely of carbon atoms, rolled up like a sheet of wire mesh into a cylinder just a few nanometers across—that’s roughly 50,000 times thinner than a strand of human hair. Discovered in 1991 by Japanese scientist Sumio Iijima while examining carbon materials under an electron microscope, these tubes are incredibly strong—tougher than steel yet much lighter—and they’re excellent conductors of electricity and heat. They also have a massive surface area for their tiny size. These features make CNTs useful in many areas, such as electronics and medicine, but we’re focusing on how they enhance Radar Absorbing Materials (RAM) for stealth technology in military aircraft. Picture CNTs as mini straws that snag and zap radar wave energy, keeping aircraft off enemy screens.

There are two key kinds: single-walled CNTs (just one layer) and multi-walled CNTs (several tubes nested inside each other). Multi-walled ones are popular in RAM because they’re simpler to make and blend into mixed materials.

How Carbon Nanotubes Work in RAM

In RAM, CNTs don’t go solo—they’re mixed into materials like plastics or adhesives to form blends that absorb radar waves rather than reflect them. Radar waves are electromagnetic waves in the microwave band, similar to Wi-Fi but used for detecting objects. When these waves hit a plane with CNT-laced RAM, the tubes act like a web of mini antennas and power drains.

Here’s a straightforward rundown:

- **Electrical Conductivity:** CNTs conduct electricity really well, so they spark tiny currents when waves smack into them. This converts the wave’s energy into heat via “ohmic losses”—the energy dissipates as mild warmth that fades harmlessly
- **Dielectric Properties:** Stuck in a plastic base, CNTs trigger “polarization,” where the material’s bits shift with the wave, causing rubbing and more heat loss
- **Multiple Reflections and Trapping:** Their tube form and big surface make waves ping-pong inside the stuff, losing power each time until they’re gone. Mixing with magnetic bits like ferrites amps this up
- **Size Matters:** Tinier CNTs (around 8 nm wide) grab high-frequency waves better, while bigger ones (30–50 nm or more) tackle lower ones. Research shows that mixing sizes tunes the material for wide coverage, such as 2–18 GHz, covering most military radars.

The aim? Shrink the radar cross-section (RCS)—how big the plane looks on radar—to bird-sized or smaller. CNTs rock because they’re light (no bulky metals), bendy for curvy surfaces, and cheap to mass-produce. But hurdles exist: they clump during mixing, reduce cutting effectiveness, and require the mix to handle heat and weather without breaking down. For instance, one method weaves CNTs onto fibers then sets them in glue, hitting 99% absorption in some bands.

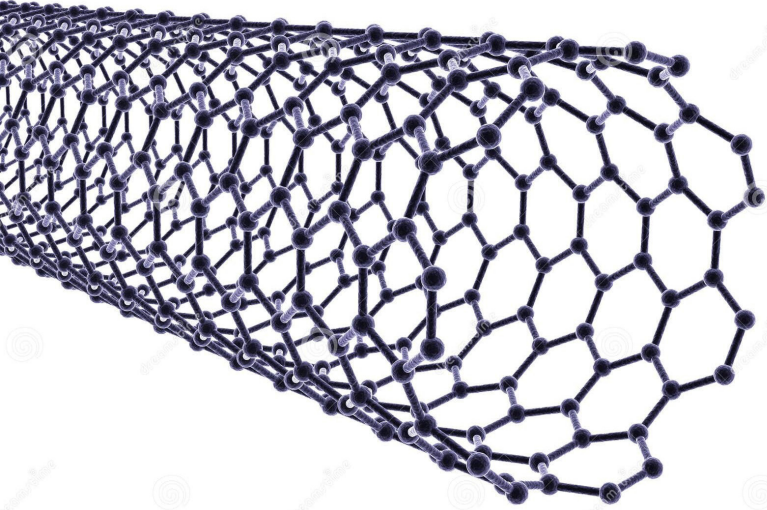
Applications in Stealth Technology

CNTs stand out in military gear, especially on planes and

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What Are Carbon Nanotubes?

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vehicles that need to evade radar. They're often teamed with other carbon stuff like graphene or fibers for top results. For example:

- In jets like the F-22 Raptor or B-2 Bomber, CNT-boosted coatings suck up radar from all sides, slashing detection distance
- Patents detail CNT-laced fibers in bases that layer up: one barely reflects, another zaps energy, cover-

ing low frequencies (0.1 MHz) to 60 GHz

- Studies show CNT-plastic blends with just 1% CNTs nail strong absorption in slim layers (under 2 mm), ideal for drones or missiles without extra heft
- They're tweakable too: Adding metals like iron or cobalt ramps up magnetic losses for a wider shield.

Outside planes, CNTs in RAM eye ships, tanks, and even soldier gear to dodge radar. Future upgrades could make them “switchable” (flip on/off with electricity) for smart, changing stealth.

Conclusion

Carbon nanotubes shake up RAM by offering lightweight, powerful ways to absorb radar waves via conduction, snagging, and heat flipping. They're a major upgrade over traditional iron paints, delivering better wideband absorption to meet today's stealth demands. As research advances, look for smarter CNT mixtures that could make invisibility cloaks a reality—not only for jets but also for everyday tech. ➤



The Lockheed Sea Shadow:

PIONEERING NAVAL STEALTH TECHNOLOGY



BILL KOLB

MONDAY DOCENT

In the shadowy realm of Cold War innovation, the Lockheed Sea Shadow (IX-529) emerged as a groundbreaking experimental stealth ship, designed to evade radar detection and test advanced hull configurations. Developed by Lockheed's Skunk Works division in collaboration with the U.S. Navy and the Defense Advanced Research Projects Agency (DARPA), the project began in the late 1970s as an extension of stealth principles from aircraft like the F-117A Nighthawk to maritime vessels. The goal was to reduce a ship's radar cross-section and acoustic signature, making it nearly invisible to enemy surveillance, while exploring stability in rough seas.

Construction of the Sea Shadow commenced in 1983 inside the secretive Hughes Mining Barge (HMB-1), a floating covered enclosure in Redwood City, California, to shield it from Soviet spy satellites. Completed in 1985, the vessel was never commissioned for operational use but served as a testbed for cutting-edge technologies. Its unique Small Waterplane Area Twin Hull (SWATH) design featured two submerged cigar-shaped pontoons connected to an angular upper structure with 45-degree faceted surfaces, reminiscent of the F-117's radar-deflecting geometry. This configuration minimized the waterplane area for exceptional stability, even in high waves, and bounced radar signals, significantly reducing its detectability.

Technically, the Sea Shadow measured 164 feet in length, 68 feet in beam, with a draft of 14-15 feet and a full-load displacement of about 560 tons. Powered by diesel-electric engines driving twin propellers, it achieved

speeds of 10-14 knots. It required a minimal crew of four: a commander, helmsman, navigator, and engineer, emphasizing automation for reduced manning. Additional stealth features included special coatings to absorb radar waves, muffled engines to reduce noise, and no armament, as it was purely experimental.

Testing occurred primarily at night in the 1980s and 1990s off California's coast, validating concepts like signature control and seakeeping. Despite its successes, the program faced challenges; the ship was declassified in 1993 but remained docked until 2006, when it was stricken from Navy records. Attempts to preserve it as a museum piece failed, leading to its scrapping in 2012.



Though the Sea Shadow never saw combat, its legacy endures. Technologies from the project influenced modern naval designs, including reduced radar profiles on submarine periscopes and the U.S. Navy's Zumwalt-class destroyers. It also inspired pop culture, notably the stealth vessel in the 1997 James Bond film *Tomorrow Never Dies*. The Sea Shadow stands as a testament to innovative engineering, proving that stealth could conquer the seas as it had the skies. ✈

The F-117A Nighthawk



PIONEERING STEALTH IN AVIATION

Cory W. Watts

BILL KOLB

MONDAY DOCENT

The Lockheed F-117A Nighthawk, often dubbed the “Stealth Fighter,” represents a groundbreaking leap in military aviation technology. Developed in secrecy by Lockheed’s Skunk Works division during the late 1970s and early 1980s, the aircraft first flew in 1981 and entered operational service in 1983. Conceived in response to escalating Cold War threats, the F-117A was the world’s first operational aircraft designed primarily around stealth principles to evade enemy radar detection. Its unconventional, angular silhouette and advanced materials allowed it to penetrate heavily defended airspace and deliver precision strikes with minimal risk of interception. Although officially retired in 2008, the Nighthawk’s legacy endures in modern stealth platforms like the F-22 and F-35. This article delves into the key stealth features that made the F-117A revolutionary: its faceted, angular surfaces, radar-absorbent materials (RAM), and specialized cockpit canopy coating.

At the core of the F-117A’s stealth capability is its distinctive faceted design, composed of flat, angular panels that scatter radar waves away from their source. Unlike traditional aircraft with smooth, curved surfaces that reflect radar energy directly back to detectors, the Nighthawk’s geometry uses two-dimensional facets to deflect electromagnetic waves at oblique angles. This

approach was originally proposed by Soviet physicist Pyotr Ufimtsev in a 1962 paper that theorized that a faceted surface would diffuse radar energy, resulting in a far smaller radar cross-section (RCS). Over a decade later, Lockheed’s Skunk Works used that theory to model a faceted design that minimized an aircraft’s RCS to approximately 0.003 square meters, comparable to that of a small bird. The swept wings and the V-shaped tail further enhance this deflection, reducing corner reflections where radar waves might otherwise amplify. Engine intakes are screened with composite grids, and exhaust ducts transition from circular to slotted sections to minimize turbine blade returns. These design choices, while sacrificing aerodynamic efficiency and necessitating a fly-by-wire system for stability, rendered the aircraft nearly invisible to contemporary radar systems.

Complementing the angular architecture is the extensive use of radar-absorbent materials (RAM), which absorb rather than reflect incoming radar energy. The F-117A’s outer skin is coated with specialized RAM formulations, including iron ball paint—a polymer that embeds microscopic iron or ferrite spheres that generate magnetic fields to dissipate radar waves as heat. This coating, applied in layers, covers the entire airframe and is supplemented by carbon-based composites in high-exposure areas to enhance absorption across a broader frequency range. During production and maintenance,

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The F-117A Nighthawk

PIONEERING STEALTH IN AVIATION

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RAM was applied as linoleum-like sheets bonded to the surface and later as spray-on paint, with precise environmental controls to avoid defects such as air bubbles that could compromise stealth. Ground crews meticulously sealed joints with conductive paste and reapplied RAM after flights, as even minor damage could increase detectability. This material integration reduced the RCS by an order of magnitude, allowing the Nighthawk to operate undetected in operations such as the 1989 Panama invasion and the 1991 Gulf War, during which it flew over 1,300 sorties without a single loss to enemy fire.

A particularly innovative stealth feature is the coating on the F-117A's cockpit canopy, which balances radar evasion with pilot visibility. The canopy glass is treated with a transparent conductive layer, often made of indium tin oxide or similar materials, that absorbs radar waves without significantly impairing optical clarity. This coating prevents radar reflections from the cockpit interior, including the pilot's helmet or instruments, which could otherwise generate detectable signatures. When applied as a thin film, it maintains the canopy's aerodynamic shape while reducing the overall RCS contribution in a typically radar-vulnerable area. This feature exemplifies Nighthawk's comprehensive approach to stealth, where even transparent components are engineered for low observability. Along with infrared-suppressing exhaust designs and subsonic speed limits to avoid sonic booms,

these elements ensure comprehensive multispectral stealth.

The combination of these features, the angular deflection, RAM absorption, and specialized coatings, made the F-117A a game-changer in warfare, allowing surprise attacks on high-value targets like command centers and air defenses. However, the design imposed some trade-offs: limited speed (Mach 0.92 maximum), no afterburners to reduce infrared signatures, and a payload restricted to internal bays for two 2,000-pound bombs. Maintenance was labor-intensive, requiring robotic precision for RAM reapplications to keep exact surface tolerances. Despite these challenges, the Nighthawk's success in conflicts proved the viability of stealth, influencing later aircraft that use curved surfaces for better aerodynamics while maintaining core principles.

In retrospect, the F-117A not only evaded radar but also redefined aerial combat, proving that invisibility could outweigh speed or firepower. Its technologies continue to evolve in today's stealth fleets, underscoring its enduring impact on military strategy. ➤

The RAH-66 Comanche

AMERICA'S FIRST STEALTH HELICOPTER

BARRY BROWN

MONDAY DOCENT

The U.S. Army began building a new generation of helicopters after the Vietnam era, featuring the Sikorsky UH-60 Black Hawk and the Boeing AH-64 Apache, to combat the Soviet threat in Europe. The Army then looked to replace its smaller, older scout or reconnaissance helicopters from the Vietnam era. The plan was to first create both a light utility helicopter and a small attack helicopter using many of the same parts to offset production costs. This effort became known as the Light Helicopter Experimental (LHX) program.

structure and final assembly, while Boeing focused on its sensors, electronics, and support systems. Each company also contributed parts to the other.

The result was the Reconnaissance Armed Helicopter, RAH-66 Comanche, designed to “see without being seen.” Its quiet design, advanced sensors, and ability to share information allowed it to find targets while it was still difficult for enemies to detect. This was a major improvement over earlier helicopters, which could be heard by their telltale blade slap long before they arrived. The design team followed the Lockheed Skunk Works team, which built the F-117A, and utilized many of



The Army studied many early designs for the LHX, but the experience from Vietnam showed that helicopters needed to be more difficult to detect and better able to survive in combat. These goals strongly shaped the program, and the Army decided to focus on a single reconnaissance-and-attack helicopter and to drop the utility version.

Boeing and Sikorsky teamed up to build the new aircraft, with Sikorsky leading work on the helicopter's

their technological advances in the RAH-66.

The Comanche achieved low radar cross-section (RCS), infrared, acoustic, and visual signatures through fuselage shaping, radar-absorbing materials (RAM), internal armament and landing gear, along with its compact size. Its unique exhaust system mixes engine gases with cool air to reduce IR signature, eliminating the need for jamming equipment.

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The RAH-66 Comanche

AMERICA'S FIRST STEALTH HELICOPTER

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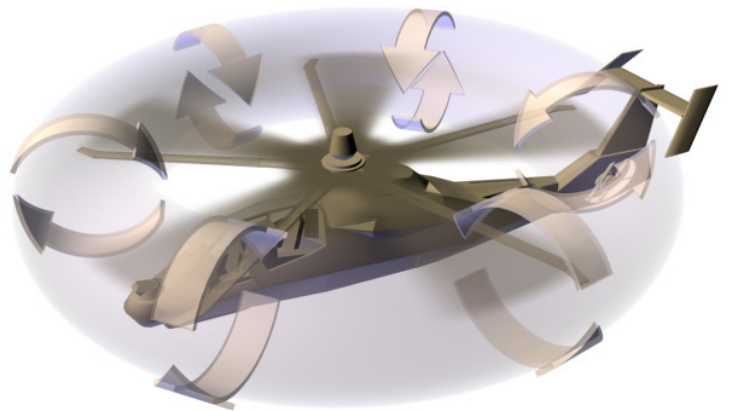
A new bearing-less main rotor (BMR) design—dubbed “Pentaflex”—featured five composite blades and eliminated traditional bearings. The Army’s requirement for exceptional yaw control led to the adoption of a large, protected ducted “Fantail” instead of a conventional tail rotor, addressing noise, safety, and performance concerns.

Advanced systems gave the Comanche a greater target acquisition range—40% further than existing helicopters—and improved FLIR sensitivity. Pilots had helmet-mounted displays with larger fields of view and digital mapping. The aircraft could be fully operated from either seat.

Protection against nuclear, biological, and chemical threats – a real threat during that time - included pressurized cockpits and maintenance-free air filtration. The composite fuselage resisted damage from decontamination cleaners, and EMP tolerance was twenty times better than prior aircraft. Extensive use of composites lowered both weight and costs.

On February 22, 2004, the Department of Defense canceled the Comanche program, even though Army leadership recognized its advanced technology and agility. Even at this time Army Lt. Gen Richard A. Cody, Army deputy chief of staff, said “. . . this team... built a tremendous aircraft. It is the most flexible, most agile aircraft we have produced in this country ... tremendous flying characteristics and leap-ahead technology that will help us as we move forward. A similar sentiment was also registered by former Army Chief of Staff General Peter Schoomaker: “Much of what we’ve gained out of Comanche we can push forward into the tech base for future joint rotor-craft kinds of capabilities. Think Osama Bin Laden mission in 2011.

Sikorsky’s MH-60X Black Hawk, S-97 Raider, Sikorsky-Boeing SB-1 Defiant, and Airbus H-160M Guépard are current advanced helicopters that feature stealth capabilities resulting from the RAH-66 program. ➤



The Stealth Black Hawk Helicopters

USED IN THE BIN LADEN RAID

BARRY BROWN

MONDAY DOCENT

On May 3rd, 2011, there was a buzz going around the Aviation Community, not to mention the world press corps. This was the day the US Army's 160th SOAR (A) "Night Stalkers" flew two helicopters with US Navy SEALs in the raid that killed Osama bin Laden in Abbottabad, Pakistan. The next morning, there were photographs of an odd-looking helicopter tail section hanging over the wall of bin Laden's compound. That did not look like what we thought they were flying, but looked like a Stealth Black Hawk. How had this technology been kept out of the public's eye before this and since? Well, it had been in plain sight, only it was the RAH-66.

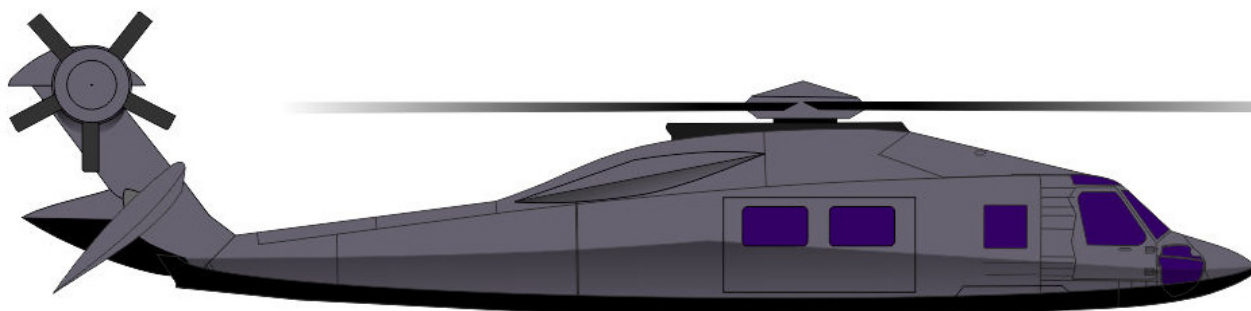
Sikorsky, who designed and built the UH-60 Black Hawk, authored a report in 1978 titled "Structural Concepts and Aerodynamic Analysis for Low Radar Cross Section (LRCS) Fuselage Configurations" that used the UH-60 as a baseline for their study. This study highlighted the need to adjust the incline of exterior body panels in

the same way as in stealth aircraft. They also highlighted adverse effects on helicopter performance and stability with these modifications. This issue would show up three decades later in the Bin Laden raid.

The research and development of the RAH-66 by Boeing-Sikorsky used that study, competing projects by Hughes and McDonnell Douglas, plus the technology from the Lockheed F-117A project, to begin the design of the Stealth Black Hawk. If you look closely at the tail section on the wall of Bin Laden's compound, you will see the same faceted tail section in the RAH-66.

How can a military helicopter become stealthier or less noisy? Re-designing a current UH-60 using composite materials, faceted rivet-free or smooth fuselages painted with the "Have Glass" system, reduced or no external store mounts, and to change the main and tail rotor system components and look. The tail section shown on Bin Laden's wall had a shiny "silver" color scheme, not dark like then UH-60's or in Hollywood movies. That tail

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AG
UGO CRISPONI
High Quality Illustrations



The Stealth Black Hawk Helicopters

USED IN THE BIN LADEN RAID

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section also had a tail rotor hub cover that resembled a dome, which was also part of the new main design. The domes would reduce radar cross-section, reduce aircraft identity, reduce drag by streamlining airflow and reducing vibrations, and protect the components.



The use of newer composites for the main rotor and tail rotor blade materials and swept wing tips also reduces the friction caused as they pass through the air. If you think of a Peregrine Falcon's swept wing makeup and how they silently approach their prey, you will have an idea of how this design helps these blade tips reduce the acoustic signature. That night, the Black Hawks entered the compound with such stealth that neither the Pakistani air nor ground forces heard them, even though they knew they would be coming.

The design of this helicopter worked, but Sikorsky's study mentioned earlier predicted an inverse effect on helicopter performance. The aerodynamic phenomenon known as the Vortex Ring State is a dangerous condition in which a helicopter descends into its own downwash. Instead of flowing smoothly down through the rotor system, the airflow circulates upward around the blades in a doughnut-shaped vortex, destroying lift. The helicopter can continue sinking even with power applied, resulting in a faster sink rate. Normal rotor wash pushes air straight down and away to produce lift, but at low airspeed and high rate of descent, the rotor begins to recirculate air. If you are at high density altitude, low

forward airspeed, and between 20-100% power applied, that rotor becomes inefficient and turbulent, causing a loss of lift. The remedy is to recognize the condition and vibrations, lower power, and fly out of it. During the Bin Laden raid, on short final to the compound, with higher than predicted temperatures, high obstructions around the compound that cause the airflow to be disrupted, heavily armed troops fast roping, so you cannot perform the emergency procedure without endangering the troops. The pilot could only apply forward motion, which resulted in the tail landing on the wall, but saved the troops.

Is the 160th SOAR (A) still flying this type of helicopter or a newer version? It is not in the public or press realm, and both the 160th and the government are mum on the subject. I found two other pictures of similar UH-60Xs in a search; one was a grainy version in the air somewhere in Afghanistan in 2020, and another was of one with its whole aircraft intact, with the tail section on top of a wall in a desert environment (location/date unknown).

The author researched numerous trade, military, and technology articles and documents during the research to ensure the most factual representation of this aircraft. There are other photographs of a stealth Black Hawk, but they do not show swept-blade tips or the rotor-head domes. ➤



Back in Black

By the pricking of my thumbs
Something wicked this way comes

- *Macbeth, Act 4 Scene 1*

DON COX

SATURDAY DOCENT, TUESDAY ARCHIVES

Visitors often ask about our F-117A, typically variations of the same question: “Why doesn’t it look black like in the photos?” or “Did the Air Force make you remove the paint because it’s classified?” My usual reply is: “Would you like the short or long answer?” If they choose short, I explain that the Air Force not only stripped the paint but also the underlayer and leading edges, which are crucial to the plane’s stealth - its “secret sauce” — and are indeed classified. That takes about 300 words or three minutes to explain.

If, however, the visitor has a bit of time on their hands, they might opt for the long answer: “I don’t know.” Three words, one second, but those three words make for a nice little segue into the story of the only time in the F-117A’s operational history when a Nighthawk was taken down.

The story’s “what” is the easy...and boring... part: at 8:15 p.m. on 27 March 1999, F-117A #82-0806, named “Something Wicked”, was shot down near the village of Budanovci in northwestern Serbia. The Serbs had fired two SA-3 Goa missiles at the plane, one of which detonated close enough to the Nighthawk to take off part of a wing and cause it to spin out of control. Its pilot, Lt. Col. Darrell Zelko (callsign Vega-31), successfully ejected and was rescued some six hours later.

The “how” and the “why” of the story are far more interesting. How could the Serbs shoot down a plane that, for all intents and purposes, was invisible to their radar systems? With, of all things, a missile system dating back to the early ‘60s? After all, the Nighthawk had flown an estimated 1,300 sorties in Desert Storm just eight years earlier in the most hostile environment ever experienced by combat pilots with nary a scratch, and the Iraqi air defenses were far superior to what pilots encountered in Operation Allied Force. After action reports by so-called armchair pilots - the aviation world’s equivalent of Monday morning quarterbacks - almost

universally attributed the shutdown to blind luck, but a deeper dive into the incident reveals that luck had very little to do with it. Instead, it was the Serbs’ ability to answer three critical questions: when, where, and how.

During Operation Allied Force, the F-117As departed from Aviano Air Base in Italy. Aviano is roughly 400 miles from downtown Belgrade, which is about a 45-minute flight for an F-117A cruising at just over 600 knots (0.8 Mach). Among the group of plane spotters gathered at the end of Aviano’s runway, there were some Serbian nationals who would call back home with a heads-up: “A couple of (*fill in the relevant plane name*) heading your way. You should see them within the hour.” At just past 7:00 p.m. on March 27, 1999, Vega-31 and three other F-117As took off from Aviano and were reported by the plane spotters in Serbia. Considering a refueling stop in Hungary along the way, Vega-31 would be over Serbia around 8 p.m.

The answer to the question of where was provided by NATO’s mission planners themselves. For the past three nights running (Nighthawks *always* flew at night), the F-117As had been flying the same ingress and egress routes to strike targets in the Belgrade area, routes that took them over the vicinity of Budanovci in northwestern Serbia. Planners had apparently felt so confident in the F-117A’s stealthiness that it not only sent the Nighthawks along the same routes they’d been using but also sent them inbound that evening without the usual Suppression of Enemy Air Defenses (SEAD) package of Prowlers, Phantoms, and Vipers to provide cover; those had all been grounded because of the weather. And because the Serbs were monitoring NATO radio communications, they knew the F-117As would be coming to the party without their escorts.

Which left only one question remaining: the how. How do you shoot down a plane that you can’t see? For starters, Colonel Zoltan Dani, commander of the 3rd

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Back in Black

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Battery of the 250th Missile Brigade, refused to accept that any plane was truly invisible (in a 2005 interview, he referred to the Nighthawk's so-called stealthiness as a "marketing ploy"). For the past several years, he'd been studying any material he could get his hands on, and he felt that with the right tools, he could defeat stealth. As it turned out, the right tools were a missile/radar system dating back more than 30 years, long before stealth was a twinkle in Lockheed's eye.



The P-18 (NATO "Spoon Rest"), a Soviet-designed system that first entered service in 1970, was the early-warning radar Dani used to initially acquire the F-117A. The

P-18 operates in the low meter-length VHF range, making the Nighthawk's RAM and facet shape - optimized for centimeter or millimeter wave radar - less efficient. It had detected the Zelko's F-117A at a range of about 14 miles, but because of its low frequency, the P-18 wasn't able to provide tracking information to the missile; for that, Dani's unit would need to utilize the battery's SNR-125 (NATO "Low Blow") fire control radar. Low Blows operate at a much higher frequency and wouldn't normally be able to detect a Nighthawk. Compounding the issue was how Serb anti-aircraft missile units trained: no more than 20 seconds of active radar (to reduce the chances of the aforementioned SEAD aircraft sniffing them out), and no more than three 20-second cycles before packing up and moving the whole system to another location. But of course, that night there was no supporting SEAD package for 82-0806.

In the first two cycles, 3rd Battery saw nothing. But immediately on the third cycle, a blip appeared - "Something Wicked" was coming their way. The reason the Low Blow was able to acquire the Nighthawk was that its 20-second window intersected with a six-second window of the F-117A, the six-second cycle of the weapons bay doors opening and closing as Zelko released his two 2,000-pound GBU-27s. Of the four Nighthawks in

Serbia's airspace that night and of the eight active anti-aircraft missile batteries, only Zelko's was "captured" on radar precisely because he'd dropped his bombs at the exact moment that 3rd Battery's radar was looking for him.

In this story's *denouement*, 3rd Battery's second-in-command, Lt. Col. Djordje Anicic, fired two S-125 missiles at the target when it got within a range of about 6 miles. One of the SA-3s malfunctioned, but the other blew off part of the Nighthawk's port wing, forcing pilot Lt. Col. Zelko to eject. Zelko was subsequently rescued, but the plane came down mostly intact in a farmer's field outside the village of Budanovci, some 28 miles northwest of Belgrade. Almost immediately after the shootdown, the Serbs invited the Russians to examine the wreckage and - for a price - take whatever they found useful. The Chinese also showed up at the scene, supposedly buying stealth debris from local farmers at exorbitant prices.

Incidentally, another counter to the "it was all luck" argument is the fact that five weeks later, Dani's 3rd Battery scored the only other SAM kill of the 78-day conflict, a SEAD F-16 flown by the 555th Fighter Squadron's commander, Lt. Col. Dave Goldfein. (He later ascended in rank to be a Four-Star General and Chief of Staff of the Air Force.)

It's interesting to think that, as you're reading this, there's a docent in a Belgrade museum standing in front of an F-117A - *their* F-117A (or more accurately, *the leftovers* of their F-117A) telling museum visitors this very story... but from a completely different perspective. ➤



Stealth Skins

How Modern Military Planes Hide from Radar

BILL KOLB

MONDAY DOCENT

Introduction

When the F-117A Nighthawk first appeared over Baghdad in 1991, it demonstrated that radar invisibility was not merely theoretical but operationally achievable. Air defense systems designed to detect and engage aircraft struggled to track them effectively. While public attention focused on its distinctive angular geometry, engineers recognized that shaping alone could not eliminate radar returns. Residual scattering, particularly from edges, seams, and surface discontinuities, necessitated a complementary solution grounded in materials science.

Stealth, therefore, emerged as a combined function of geometry and material engineering. Rather than relying solely on deflection of radar energy, the F-117A incorporated materials capable of absorbing and dissipating electromagnetic energy before it could be reflected to a radar receiver.

Stealth in the '60s & '70s

The F-117A Nighthawk and the SR-71 Blackbird were early pioneers in stealth. Both used iron-ball paint, which consists of tiny iron spheres (carbonyl iron or ferrite) mixed into a thick epoxy or polymer paint. When radar waves hit the paint, the iron particles oscillate, converting electromagnetic energy into a small amount of heat that dissipates harmlessly.

The coating is essentially a single thick layer sprayed or glued onto the metal (or composite) skin. On the F-117A, it added roughly 2,000 pounds of weight, requiring careful application—initially by workers in protective gear, later assisted by robots—to maintain precise thickness. The SR-71's version also helped manage the aircraft's extreme aerodynamic heating at high speeds; its dark color aided heat radiation while providing some radar absorption.

Iron-ball paint worked, but it had limitations. It wore off easily from weather, flight stresses, or maintenance, often requiring frequent repainting. Sections could crack or peel, and it was most effective against a narrow range of radar frequencies. Designers therefore relied heavily on the F-117A's sharp, faceted shape to deflect waves away from enemy radars.

Material-Based Stealth: A Layered System

Modern stealth aircraft like the F-22 Raptor, F-35 Lightning II, and B-2 Spirit employ more advanced multi-layer radar-absorbent materials (RAM) and radar-absorbent structures (RAS). These are not simple paints but are integrated into the aircraft's composite skin, often carbon-fiber reinforced. The layers function like a tuned "sandwich" to absorb radar energy across a broad spectrum of frequencies.

A typical layered stack might include:

1. **A tough topcoat** that protects against rain, heat, sunlight, erosion, and wear while remaining largely radar-transparent (allowing waves to pass through with minimal reflection). This outer layer is usually a durable polymer or elastomeric material that is flexible enough to withstand high speeds and environmental stress. It can also contribute modestly to reducing the aircraft's infrared signature.
2. **One or more absorbing layers** that dissipate radar energy as heat. These contain particles or patterns tuned to specific bands (e.g., X-band commonly used by fire-control radars). Materials include carbon black, carbon nanotubes, graphene, and magnetic particles such as ferrites. Incoming waves induce vibrations or micro-currents in these particles, converting energy into thermal dissipation. Multiple tuned layers enable "broadband" absorption effective against diverse radar systems.

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Stealth Skins

How Modern Military Planes Hide from Radar

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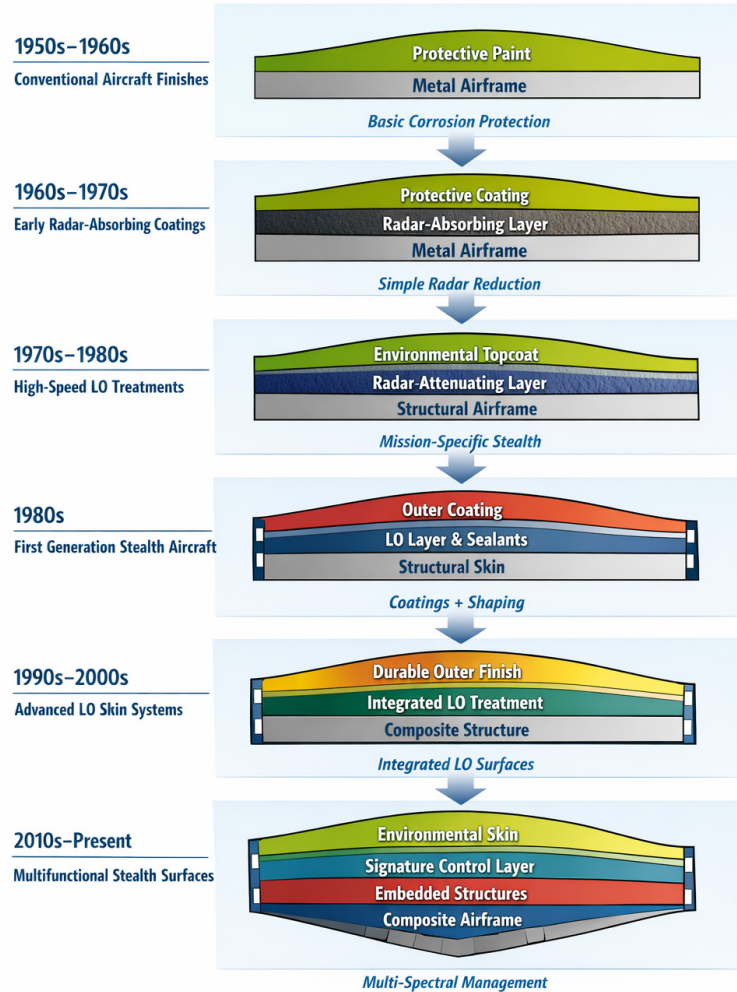
3. A **honeycomb or foam spacer layer** that separates the absorbing layers and promotes destructive interference (phase cancellation) of any residual reflections—analogueous to noise-canceling technology but for electromagnetic waves. Honeycomb cores (often coated or impregnated with absorbers and made of materials like Kevlar, fiberglass, or carbon fiber) are favored for their high strength-to-weight ratio and ability to bear structural loads while remaining lightweight.
4. A **conductive back layer or primer** applied to the composite airframe (carbon-fiber-reinforced plastic, sometimes with titanium elements). This reflects any remaining waves back into the absorbing layers for further attenuation and provides electrical grounding and structural integrity.

The effectiveness of this architecture comes from sequential attenuation: transmission through a low-reflectivity outer surface, magnetic and dielectric losses in the absorbing layers, phase cancellation in the spacer, and minimal residual reflection from the non-metallic base. Radar returns are often reduced to levels indistinguishable from background clutter.

Conclusion

The evolution of stealth technology reflects a shift from simple coatings like iron-ball paint to fully integrated material systems. Early solutions proved radar absorption was feasible, but today's aircraft achieve superior performance through precise layering, frequency tuning, and embedding RAM/RAS directly into the airframe. By combining faceted or curved geometry with advanced composites and multi-layer materials, modern stealth platforms do not merely deflect radar—they actively suppress and dissipate it. This has fundamentally redefined aerial warfare, where detectability depends less on size or speed and more on mastery of electromagnetic interactions at the material level. ➤

Evolution of Stealth Coating Technology



Restoration Ties Back to Active Duty

A Reunion with our F-117A (85-816) “Lone Wolf”

STEVE SWARTOUT

RESTORATION VOLUNTEER

My name is Steve Swartout, and I am a USAF veteran who served from 1984 to 1994 with the stealth program from '88 to '94 as an avionics tech and maintenance instructor. I also participated with the 37th Tactical Fighter Wing (TFW) in Operation Desert Storm. I will never forget the night that the Museum's F-117A 85-816 dropped that historic first bomb on 1/17/1991. I was a member of the 416th TFS, and 85-816 was flying with the 415th TFS.

I came to volunteer at Evergreen after being encouraged by my wife, Deena. She had bought tickets for the initial unveiling of Nighthawk as a surprise for me. That evening, I was walking around the aircraft and met [Exhibits Manager] Scott Malandrone, who had come up from Castle Air Museum to help with the event. We got to talking, and I was able to go behind the curtain and take a closer look at the aircraft before the show. After that event, I started volunteering in Restoration, and I come up when I can on the weekend to volunteer and help with the Nighthawk events and the Air Show weekend.

As for working on 816, I've spent hours removing screws and cleaning up adhesive residue from the aircraft in preparation for restoration. Scott and I installed the engine inlet grids and blow-in doors. It was a real highlight when I sat in the cockpit of 816 for the first time in 30 years to the month, as it had been 30 years to the month since I was in the cockpit of a stealth fighter.

A real highlight of volunteering at Evergreen is the time I can spend sharing with the guests who are amazed by the aircraft. As you walk around the aircraft, you will see that the avionics racks are down, which enables access to the avionics bays. Those bays housed most of the avionics and served as my office during my time with the aircraft. It was interesting to see what was updated and what remained unchanged. It is also interesting to see the airframe in its current condition, how thin the outer skin is, and the waves in the skin. Current photos of F-117As still flying show the same waviness in the skin. With the coatings removed, you can see the scribe and cut marks in the skin from when an access panel had to be removed for maintenance and the RAM coating repaired.



It was an honor to have served with this aircraft at Tonopah, Saudi Arabia, and Holloman AFB. That honor continues, as I can share my stories and experiences while working to get the “Lone Wolf” back to how she looked in Desert Storm. ➤

Camouflaging the Lockheed Burbank Aircraft Plant



BILL KOLB

MONDAY DOCENT

In the wake of the Japanese attack on Pearl Harbor on December 7, 1941, the United States grappled with heightened fears of further assaults on the West Coast. The Lockheed Burbank aircraft plant, a vital hub for producing military aircraft such as the P-38 Lightning fighter and licensed B-17 Flying Fortresses, emerged as a prime target. Located adjacent to what is now Hollywood Burbank Airport, the facility spanned vast areas and employed thousands, making its protection paramount. Military leaders, alarmed by Japanese submarine sightings and a shelling incident off Santa Barbara in 1942, initiated “Operation Camouflage” to conceal the plant from aerial reconnaissance and potential bombings.

The task fell to Colonel John F. Ohmer, a camouflage pioneer who had honed his skills during the Battle of Britain in 1940, where his deceptions misled Luftwaffe bombers. Stationed at March Field, Ohmer was urgently summoned to Burbank just after Pearl Harbor. With authority from the U.S. Army Corps of Engineers, he assembled a camouflage engineering battalion, recruiting Hollywood’s finest talent—set designers, painters, animators, and prop experts from studios like Disney, Paramount, 20th Century Fox, Metro-Goldwyn-Mayer, and Universal Pictures. This collaboration blended military strategy with cinematic illusion, transforming the industrial site into a seemingly innocuous suburban landscape.

The camouflage efforts were elaborate and resource-intensive, costing millions and spanning over a year. The

main factory and surrounding areas, covering more than 1,000 acres. They were then draped in a massive canopy of chicken wire, netting, and painted canvas to mimic grassy fields. Airfields and parking lots were painted green and adorned with plants to resemble alfalfa crops. Fake trees and shrubs were crafted from chicken wire coated in adhesive, with chicken feathers spray-painted in shades of green for foliage and brown for realism, creating a three-dimensional effect. Burlap bungalows simulated houses, complete with barns, silos, and small

(CONTINUED NEXT PAGE)



Camouflaging the Lockheed Burbank Aircraft Plant

(CONTINUED FROM PREVIOUS PAGE)

farms featuring animals. Rubber automobiles and decoy aircraft, made from canvas scraps, ration boxes, and tin cans, dotted the faux roads and runways.

To sustain the deception, employees played active roles. Underground walkways and air ducts—disguised as fire hydrants—allowed movement without breaking cover. During breaks, workers used catwalks to hang laundry on clotheslines or reposition fake cars, simulating daily suburban life. However, the setup posed challenges: feathers often drifted into assembly areas, complicating aircraft production.

The effectiveness was tested when Ohmer flew a War Department general over the site at 5,000 feet; the general saw only typical California suburbs, validating the illusion. Additional defenses, like bomb shelters and anti-aircraft guns, bolstered security. The threat waned after the U.S. victory at the Battle of Midway in June 1942, and by 1945, the camouflage was dismantled as the war shifted. This innovative operation not only safeguarded a key wartime asset but also highlighted the ingenuity of blending art and warfare. ✈



A Summer Camp Request to the Docent Community



LEE NGO

EDUCATION DIRECTOR

As Spring Camp week came to a close in March, the Education team identified a key need and opportunity for the docent corps to contribute to the Education experience. We're able to anticipate a lot from our young campers at our camps, but we would love more support. Even with reduced cohort sizes to improve classroom management for our instructors, having an additional adult who represents the interests of the Museum makes a huge difference.

Inspired by Monday Education Docent Vivek Kalavai's willingness to support a few of our Day Camps, his enthusiasm for doing more informed me that we are now ready to open our experience to more docent support. (A special shout-out to Vivek, as our instructors reported his help was greatly appreciated.)

For Summer Camp (and possibly even our remaining Day Camps), we'd like to have a docent in the room for each cohort during camp activities. Our expectations are deliberately light and minimal. Volunteers are there to "assist" the instructors just by being there, following their lead in case a camper needs help or attention.

Here are some more details and requirements to make it successful for the docent and worthwhile to Education:

- Min. 3-hour commitment (morning: 9:00 - 12:00 or afternoon 12:00 - 3:00 per camp)
- All-Day availability = 8:30am - 3:30pm (7-hour limit per day)

- 100% volunteer (can opt out at any time)
- We'll confer with the Chair and Day Captains on time volunteered towards any corps merits
- Background checks are possible (as they will be interacting with minors)
- Availability on any day Monday through Saturday

Basic Tasks:

- Oversee campers (but no direct classroom management or counseling)
- Interact and help with activities (crafts, challenges, drawings, etc.)
- Provide another grown-up presence, especially if the instructor needs to step out for a moment
- Take photos for posterity uses (outreach, marketing, etc.)

If you are interested, please email us at education@evergreenmuseum.org. I'll be the one to ultimately coordinate everyone with our new full-time hire, which reminds me...

Meet Katie Hauser: Education's New Addition

Hello, Docent Corps! My name is Katie Hauser, and I'm excited to introduce myself. I recently joined the Museum's Education Department as the Community Program Instructor. Before coming to the Museum, I worked with Oregon State University Extension in youth development, and prior to that I was a middle school teacher in South Carolina and Georgia.



As the Community Program Instructor, I'll be helping support the development and delivery of community programs and assisting with school and youth-centered activities to help create engaging learning experiences for visitors.

I've been pleased to meet many of you already and have appreciated the welcome and information you've shared with me. I look forward to getting to know more of you and working together to connect our community with the Museum.

To connect with me, email at katie.hauser@evergreenmuseum.org or call my office at 503-587-2424 (or x2424 at the Museum).

Mystery Corner

JEAN HERKAMP

LEAD ARCHIVES VOLUNTEER

In this and future editions of the FlightPlan, Archives will provide a picture of an artifact/item for which they have no idea what it is, how it came about, or where it originated.

The following month, Archives will provide the answer or the best-guess submissions, if any. ➤

THIS MONTH'S MYSTERY: What the heck is this?

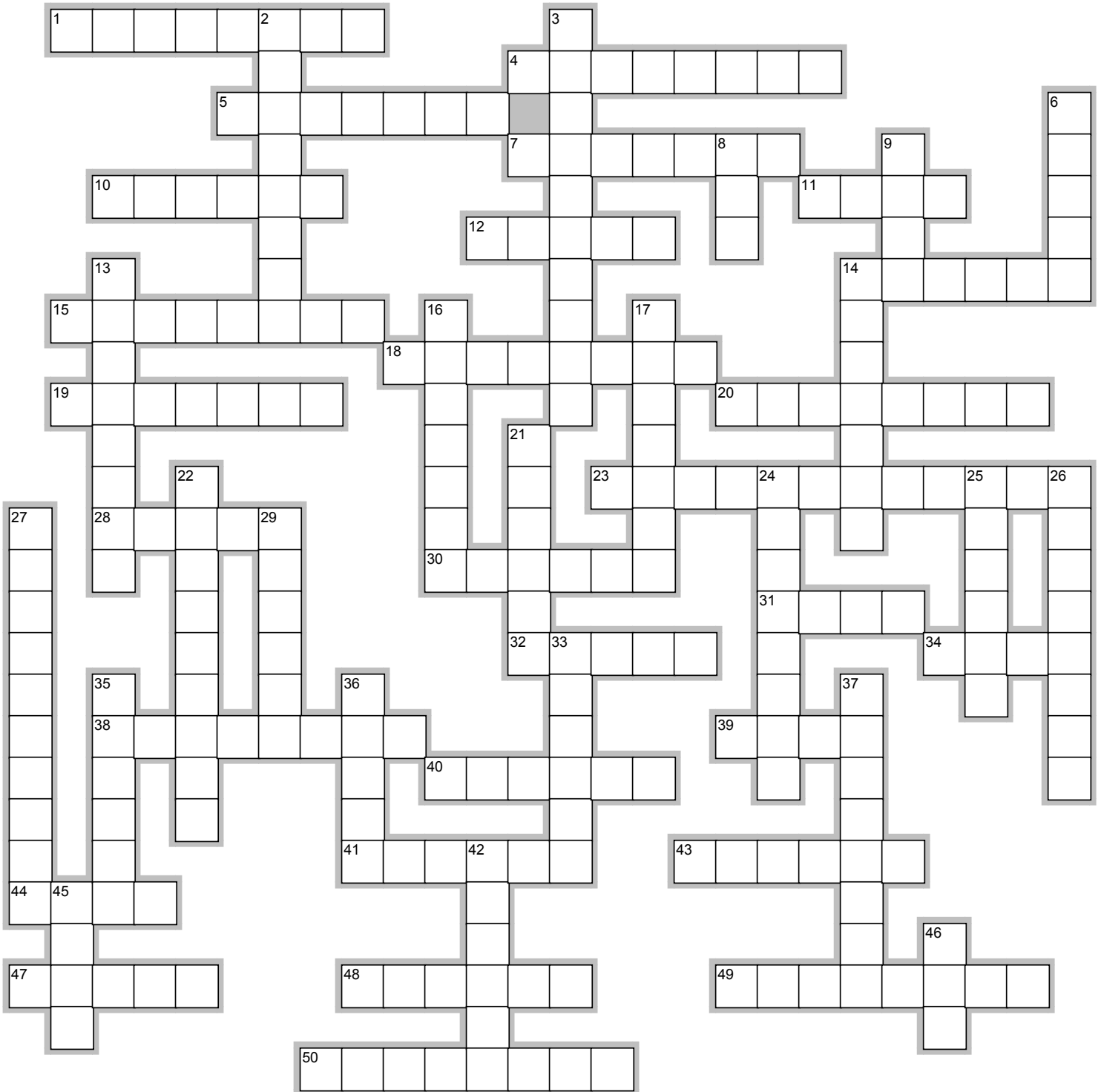


We hope someone has knowledge of this artifact, or at least can make an educated guess. Readers are encouraged to provide Archives with their best answer/guess by responding to Jean Herkamp at: jean.herkamp@evergreenmuseum.org.

Stealth Edition

DON COX

ARCHIVES & SATURDAY DOCENT



Stealth Edition - Clues

ACROSS

1. Maker of China's J-35
4. F-117A's concept design (2 words)
5. Skunk Works' CA home
7. Nighthawk's Nevada roost
10. B-2's name
11. Boeing's stealth concept aircraft Bird of _____
12. NATO's name for the Su-57
14. Mineral used in RAM
15. F-117A's final home in NM
18. F-117A's maker
19. The first military application of radar-absorbing paint was on this part of German submarines
20. F-117A's insect nickname
23. Chengdu J-20's official name (2 words)
28. SR-71's Baltic mission name GIANT _____
30. F-117A's experimental scheme Gray _____
31. D-21 mission name SENIOR _____
32. Term for "canxing" a mission
34. "Father of Stealth" Ben
38. Russian stealth pioneer Pyotr _____
39. Boeing X-36 lacks this
40. B-21's name
41. Designer's nickname for stealth features: _____ sauce
43. The project that gave birth to the Hopeless Diamond
44. Plane's loss of yaw control
47. The T in IRSTS
48. Only person to shoot down a Nighthawk, _____ Dani
49. EASM's F-117 nickname (2 words)
50. City where F-117A "Something Wicked" is displayed

DOWN

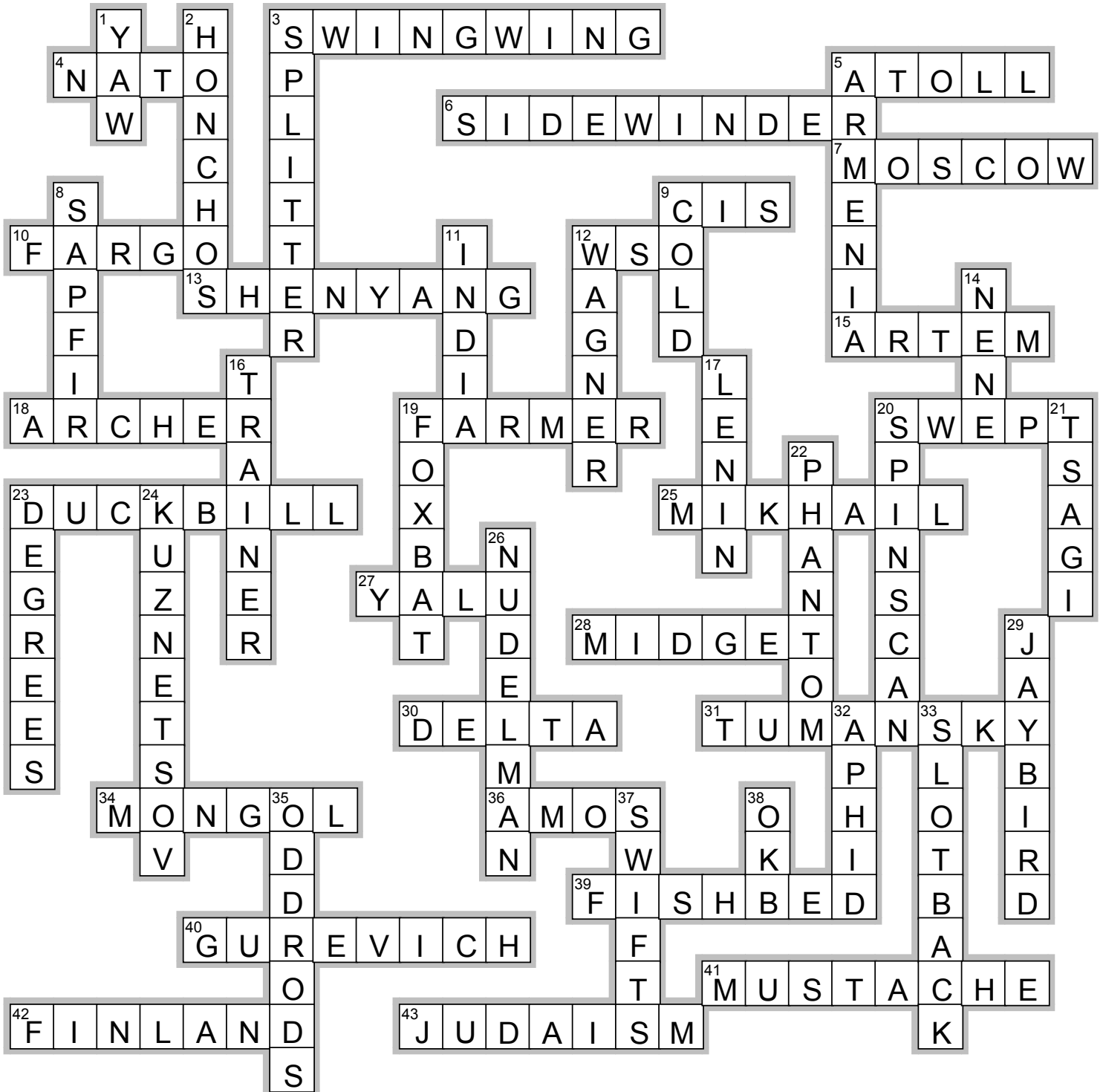
2. Metal used in F-117A construction
3. Israeli maker of stealth paint
6. The country that first experimented with stealth paint
8. Military "Roger" (abbreviation)
9. Zelko's callsign ____-31
13. The D in DLIR
14. J-20's company
16. The F in FLIR
17. The S in RCS
21. First country struck by F-117As
22. The R in RAM
24. Type of engines used in Nighthawks
25. Nighthawk's nickname "Wobblin' _____"
26. TACIT BLUE builder
27. AKA: Lockheed's Advanced Development Programs arm (2 wds)
29. Nighthawk shares an engine with this plane
33. Callsign for all F-117A pilots
35. Felon's company
36. Lockheed's _____ Overholser
37. Kelly Johnson's first name
42. F-22's name
45. HAVE BLUE's test pilot Bill _____
46. NATO name for the missile that shot down the F-117A

Note: Answers will be provided in the following month's edition. For now, the best way to work on the crossword is to print out the puzzle. We're exploring options to make it more interactive without printing.

March Issue - MiG Puzzle Answer Key

DON COX

ARCHIVES & SATURDAY DOCENT



EclipseCrossword.com

Remembering Stan

Editor's Note: At the March 5th Band of Brothers meeting, Stan deStwolinski was honored for his service and congratulated on his 95th birthday. A few days later, Stan suffered a heart attack and passed away on Sunday, March 15th. Below are thoughts from his good friend Dave Cutter, memorializing Stan's life and chronicling his many years of service.



Stan deStwolinski, a Korean War Veteran, NEVER stopped serving! During his time in the United States Army, he stepped up when Command reached out, and Stan became First Sergeant in the 116th Engineer Construction Battalion at only 20 years old! He arrived in Korea on February 1, 1951, and served there through five major campaigns in 1951 and 1952, ending up in what is now North Korea. He lived up to the challenge, and when it was time for his discharge, he was offered a commission, which he declined so he could return home to the love of his life, Virginia.

A kind, caring, and motivated young man, he was a very successful entrepreneur in manufacturing sales for ten years. Following that, he started and ran his own real estate company for many years, which was the largest in Sonoma County, California.

After retiring, Stan signed on as a docent at the Evergreen Aviation & Space Museum. His service there lasted over 12 years. He shared with me how he studied, learned, and memorized every detail about each exhibit early in his volunteer role. He was particularly fond of the Spruce Goose and led tours there for much of his time.

Stan was involved with Veterans for a long time and served as the Commander of a Veterans of Foreign Wars (VFW) Post in Nevada for several years. After moving to Oregon, he met a Veteran in Redmond wearing a "Band of Brothers" patch, and he asked about it. He was invited to a meeting and found it to be a much more relaxed gathering of Veterans than anything he had experienced before. Family and friends were welcome, there were no dues, no officers, no rules or regulations, just great camaraderie. Following that fortunate encounter, Stan introduced the Oregon Band of Brothers to McMinnville in the fall of 2010. A couple of years later, he found a wonderful new home for the McMinnville branch at the Evergreen Aviation & Space Museum. In recent years, he has also helped establish new Band of Brothers groups in Newberg and Hillsboro.

At the March 5th celebration, all of Stan's children were able to attend. The members of Stan's family, from left to right, are: John Burgardt (daughter Karen's husband), daughter Diane Herzer, Bill Morris (daughter Linda's husband), daughter Linda Morris, Patriarch Stan deStwolinski, front and center, granddaughter Katie Kirshner, daughter Karen Burgardt, and son Mark vonStwolinski.

Stan deStwolinski touched many, many hearts over his lifetime, serving continuously until it was time to depart this Earth. ✈



Band of Brothers



The McMinnville, Oregon Band of Brothers meets on the **first Thursday of each month** in the large glass-walled room to the left of the primary admissions desk in the Hercules Pavilion (formerly Aviation Museum). **Meetings run from 11:30 am to 12:30 pm**, with coffee and cookies served. More details can be found at the group's Facebook page: <https://www.facebook.com/groups/838928846550343>

JOHN BURLESON

COLLECTIONS & SUNDAY DOCENT

APRIL 2

The presenter for April is Coy Pfaff, who is with the Soaring By The Sea Foundation located in Eugene. The topic will be the Consolidated PBY.

MUSEUM MISSION

Evergreen Aviation & Space Museum is a force of curiosity and courage for kids of all ages to gain the confidence to take flight.

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