# Implementing Joint Vision 2010

## A Revolution in Military Affairs for Strategic Air Campaigns

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## *About the Author*

Col Christopher G. "Jake" Warner is the director of Doctrine Applications, Headquarters Air Force Doctrine Center, Maxwell Air Force Base (AFB), Alabama. He received a Bachelor of Science degree in physics in 1976 from the University of Southwestern Louisiana and a commission from AFROTC. He also earned a Masters in Management degree from Embry–Riddle University in 1988.

His initial assignment was to undergraduate pilot training, Class 97-02, at Vance AFB, Oklahoma. Graduating as a fighter-recommended pilot, he trained as an OV-10A pilot and forward air controller (FAC). Assigned in 1979 to 704th Tactical Air Support Squadron at Sembach Air Base, Germany, he served as a flight lead and instructor pilot and was named the Seventeenth Air Force FAC of the year. In 1982 he returned to the United States and completed training in the F-15 as a distinguished graduate. He served in the 27th Tactical Fighter Squadron and as the 1st Tactical Fighter Wing's assistant director of training.

After completing training as a B-52 aircraft commander and a distinguished graduate, he was assigned in 1984 to Griffis AFB, New York. He served as a flight lead in the 668th Bombardment Squadron and as wing tactics officer and tactics branch chief in the 416th Bomb Wing.

In 1987 he was assigned to Headquarters Strategic Air Command (SAC), Omaha, Nebraska, where he served as a bomber-tactics developer and project officer for the first US Air Force (USAF) Bomber Weapons School. Assigned double duty as SAC's command-sponsored research fellow and as a full-time Air Command and Staff College residence student in 1989 at Maxwell AFB, Alabama, he finished as a distinguished graduate and completed research on his low-observable penetrator employment.

After graduation in 1990, he was selected as a tactics developer at the new 99th Strategic Weapons Wing, Ellsworth AFB, South Dakota. He was assigned duties as the SAC

Tactics School bomber flight commander and 25th Tactics Training Squadron operations officer and was requalified as a B-52 instructor and evaluation pilot.

In 1993 he was selected as the first commander of the 99th Operations Support Squadron and later as commander of the 25th Training Squadron where his unit provided tactical-employment academic and flight training to all USAF B-52 and B-1 instructors.

After completing his squadron closure, he was assigned in July 1994 to the Joint Staff/J-7 at the Pentagon, Washington, D.C., where he served as a strategic planner developing the Joint Training System, Joint Vision 2010, and the Joint Simulation System. Selected for Air War College attendance, he graduated in 1997 and was selected as executive officer in the new Headquarters Air Force Doctrine Center and moved to his current position in May 1998.

Colonel Warner is a command pilot with more than 2,300 hours in the OV-10, F-15, and OH-58 aircraft. His decorations include the Defense Meritorious Service Medal, the Air Force Meritorious Medal (two Oak Leaf Clusters), and the Air Force Commendation Medal (two Oak Leaf Clusters). He is married to the former Ann Louise McMahon of Lake Charles, Louisiana, and they have three children, Matthew, Stephen, and Katherine.

# *Preface*

The chairman of the Joint Chiefs of Staff (CJCS) has a requirement to provide his vision and guidance to the unified commanders and services to meet the national military strategy. Gen John Shalikashvili has met this responsibility with his *Joint Vision 2010* (*JV2010*). *JV2010* is the conceptual template for how the military services should develop and merge United States (US) resources, war-fighting skills, and new technologies to achieve higher levels of joint war-fighting effectiveness. An implementation strategy is key to realizing the impact of JV2010. Such a strategy is a process in which future war-fighting operational concepts are developed into fielded war-fighting capabilities.

JV2010 implementation has begun, with the Joint Warfighting Center at Fort Monroe, Virginia, coordinating the effort among the combatant commanders, services, and the supporting battle laboratories. The United States Air Force (USAF), along with the other military services, will play a major role in implementing JV2010 as well as developing and implementing its own service vision, *Global Engagement.* This process begins with the broad JV2010 concepts and continues into service concepts that are expanded, tested, and fielded in JV2010 as joint and service core competencies, operational doctrine, and capabilities.

Using the chairman, Joint Chiefs of Staff's JV2010 operational concepts and the USAF's *Global Engagement's* core competencies for guidance, I will propose a concept for a 2010 strategic air campaign. I will describe how the campaign will impact our national resources, improve our war-fighting skills, and require new technologies. This concept is described in four structural parts: doctrine, operational concepts, organizational structures, and technology. I will conclude with a discussion of how such an air campaign is also a potential revolution in military affairs.

Of some interest—a revelation perceived during my research—is the strategic impact of the United States's national resources in comparison with those of potential adversaries around the world. I expected to find that operational doctrine and technology would be the keys to a revolution in military affairs. I was surprised to discover that the ability to maintain approximate levels of national investment and military funding in research, development, and operational tempo is the true key, when teamed with evolving doctrine and technology, to a revolution in military technology (RMA) with the United States at the lead. This ability to maintain national investment in a capable military and in research and development, while the other world-power centers continue to reduce their spending, is termed *disproportionality,* the true key to a US-led RMA.

# *Acknowledgments*

This project was based on a long-term personal interest in airpower doctrine, history, strategy, and new technology. The synergy of these interests, brought into focus by a tour on the Joint Staff while working the chairman's JV2010, combined with the airpower strategy, doctrine, and history studies from the Air War College core curriculum and electives, has enabled and energized me to assemble these thoughts.

I would like to acknowledge the contributions of several people whose efforts played a significant role helping me complete this research project. The list is long since this project has been in varying stages of development since 1989. Special thanks go to Maj Gen John Borling, who provided the early support to begin the project, and Lt Col Joe Bowden, Lt Col Don Bryant, Col Lou Buckner, Col Al Dunlap, Lt Col Mike Gentry, Col "Scotty" Scott, and Lt Col Paul Thomasson for their direction, support, guidance, and covering for me when I was needed elsewhere. Dr. Glenn Morton, Lt Col Mannie Koczur, Tom Lobenstein, Gladys Peavey, and members of the Air University Center for Aerospace Doctrine, Research, and Education staff helped me begin my thesis and researching-skill development and performed yeoman's duty with an excellent editing of my convoluted thoughts. Dr. David Blair, Dr. Lawrence Grinter, and Dr. Jim Mowbray provided expert academic advice, terrific knowledge, and encouragement. Dr. Dave Sorensen, empowered by much patience, guided my thinking and research, continually pulling me back to reality, and challenging me to continue the academic development of the strategic air campaign concept. Lt Gen John Sams expanded my concept of the strategic air campaign to include global air mobility. My greatest thanks and love go to my wife, Ann, and my children, Matthew, Stephen, and Katherine, for their unselfish support and sacrifices so I could devote myself to this project and to an exciting and successful year at the Air War College.

# *Abstract*

Implementation of the CJCS's *Joint Vision 2010* and the United States Air Force's *Global Engagement* will lead to a strategic air campaign revolution in military affairs. The strategic air campaign of 2010 is one in which national military power is used to achieve national objectives across the spectrum of conflict. A strategic air campaign can perform worldwide mobility to deter aggression or win battles and wars with application of combat power. These future air campaigns should achieve strategic objectives that prevent crisis escalation, enhance deterrence, or support other nonmilitary national objectives with timely delivery of logistical resources and people worldwide. The synthesis of today's airpower doctrine; tomorrow's dominant battle-space knowledge; JV2010 operational-concepts development; rapid and effective command, control, communications, computers, and intelligence; high-penetration, low-observable aircraft employing precision weapons, rapidly, disproportionately, and against parallel target sets; and strategic airlift providing critical resources and supporting worldwide mobility will give the joint force commander and the US military significant long-range strategic airpower capabilities to achieve national security objectives. As we complete this synthesis, the United States will experience a strategic air campaign revolution in military affairs.

Chapter 1

# Introduction

*The nature of modern warfare demands that we fight as a joint team. This was important yesterday, it is essential today, and it will be even more imperative tomorrow.* Joint Vision 2010 *provides an operationally based template for the evolution of the Armed Forces for a challenging and uncertain future. It must become a benchmark for Service and Unified Command visions.*

—John M. Shalikashvili
Chairman, Joint Chiefs of Staff

Our national security strategy's first goal is to enhance US security with military forces that are ready to fight.[1] Ensuring our military forces' readiness is a prime responsibility of the chairman of the Joint Chiefs of Staff (CJCS). As the nation's senior military leader and advisor to the National Command Authorities (NCA), he provides vision and guidance to the services and the regional and functional commands to achieve the national military strategy. The CJCS recently met this responsibility with his *Joint Vision 2010* (*JV2010*). *JV2010* is the conceptual template for how the military should develop and merge our resources, war-fighting skills, and new technologies to achieve higher levels of joint war-fighting effectiveness.[2] JV2010 is the lead joint effort that prepares the path for development of the service visions.

While *JV2010* is remarkable for its operational concepts, it is not intended to be the single, definitive source. The JV2010 implementation process proposes that the services have the primary responsibility to develop the operational capabilities, service doctrine, tactics, techniques, procedures, and technologies to achieve the chairman's broad operational concepts. Along this path to producing these new service core competencies, the associated joint doctrine and employment development must also proceed. The result will be new operational capabilities that a joint force commander (JFC) can call for from the service components to provide effectively and efficiently in the joint environment to win wars, support growing democracies, or prevent humanitarian crises from developing into military conflicts.

The CJCS seeks to implement JV2010 by providing broad guidance to the services and to regional and functional commanders in chief when they are developing their long-term investment and modernization plans. The JV2010 implementation strategy is a process in which future war-fighting operational concepts are developed into fielded war-fighting capabilities. These operational concepts should lead to doctrine refinements, operational plans, new war-fighting organizations, and weapons-system development via statements of need, operational-requirements documents, and even system specifications.[3] While JV2010 speaks to new capabilities across the service core competencies, this project will focus on the air component. Using the CJCS JV2010 operational concepts for guidance, the author will describe a 2010 strategic air campaign employing low-observable penetrating aircraft, precision-guided munitions, and global airlift mobility assets.

As the chairman has led with his vision, the services are now taking the next step. The United States Air Force (USAF) is contributing to our long-range view of decisive application of national power through war fighting, critical resource delivery, and information dominance. The USAF describes the following contributions as its six core competencies: rapid global mobility, precision engagement, global attack, air and space superiority, information superiority, and agile combat support.[4]

As part of our nation's armed forces, the USAF's primary task is first to deter and then to fight and win our nation's wars if deterrence fails. The fundamental strategic concept to accomplish this task is power projection.[5] Effective US power-projection capabilities must span the spectrum of conflict. At the low level of conflict, these 2010 capabilities should include peacetime intelligence, surveillance, and reconnaissance to prepare for future threats, to anticipate crises around the world, and to be able to surgically apply logistical support and/or firepower in a third world conflict. US national capabilities must also span to a major regional conflict or theater

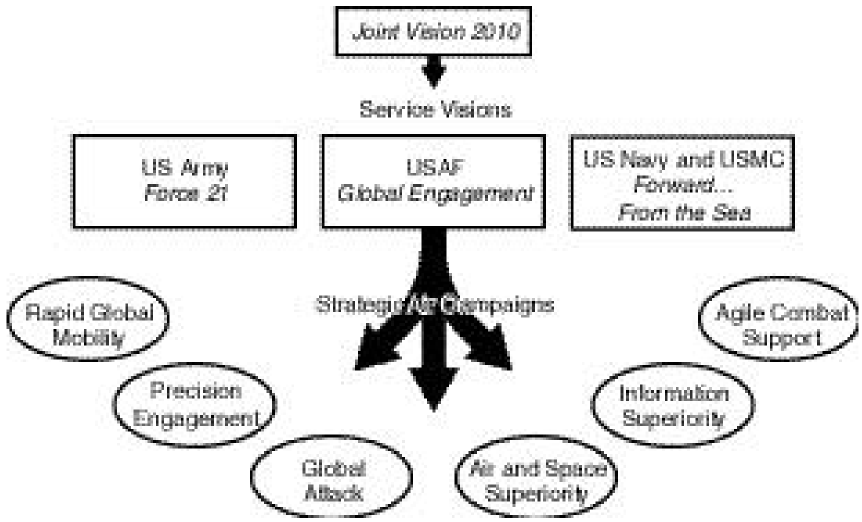


**Figure 1. Joint and Service Vision Progression to Core Competencies**

war in which the strategic air campaign is a primary means to project combat power and resources.

Air campaign planners and employers have traditionally viewed strategic airpower as sky-filled bombing and air superiority battles that win world wars. Today's and tomorrow's strategic air campaigns will have increasing applicability for attaining strategic, war-winning, and decisive goals across the spectrum of conflicts described previously. Airpower offers speed, range, freedom of maneuver, and perspective.[6] Airpower can be massive or surgical by providing time-sensitive options, capturing and disseminating crucial intelligence, delivering critical resources, or striking time-sensitive targets accurately—all with rapid global reach. This ability is increasingly important in a world with few overseas forward-basing opportunities, decreasing logistical support infrastructure, and strategic mobility limitations of powerful heavy ground forces.[7]

The USAF should continue developing the strategic air campaign, within the broad guidance of *JV2010* and *Global Engagement*, to support the national military strategy. Developing this strategic air campaign concept depends on a reasoned look at four primary factors: doctrine, operational concepts, organizational structures, and technology.[8] This paper will focus on these factors for future strategic air campaigns using airlift and refueling, low-observable (LO) aircraft, and precision-guided-munitions technologies. The discussion will examine whether these technologies are underwriting a potential "revolution in military affairs." This revolution in military affairs (RMA) potential rests on the USAF's ability to develop JV2010 operational concepts with detailed requirements and system specifications and the USAF's ability to produce a decisive military capability for the JFC and the NCA.[9]

## About Revolutions in Military Affairs and Disproportionality

> *Historically, an RMA occurs when the incorporation of new technologies into military systems combines with innovative operational concepts and organizational adaptations to fundamentally alter the charter and conduct of military operations.*
>
> —William J. Perry, PhD
> Stanford University

The RMA concept is based on a complementing structure of doctrine, operational capabilities, organizational structure, and technology.[10] While discussion of a potential RMA usually focuses on the new, exciting technology, the doctrine, operational capabilities, and organizational structures are the true keys to turning cutting edge combat power and weapons into a true revolution. Col Jeffrey Barnett, in his *Future War, An Assessment of Aerospace Campaigns in 2010,* provides a historical example supporting this point.

The French and German employment of tank technology at the beginning of World War II was quite different and ultimately decisive. The Germans developed and tested the operational capability of the blitzkrieg doctrine and the panzer division organizational structure in Poland in 1939. The results were used very effectively against the French and the Russian armies when the Germans swept across vast territories and achieved quick victories. The French, on the other hand, added the new tank technology to their existing structure and doctrine with less satisfying results.

It would be difficult to realize a strategic air campaign RMA by simply adding stealth, precision munitions, and global-mobility technologies over existing doctrine, operational capabilities, and organizations. The result would be evolutionary progression, not revolution. The true path to an RMA is usually blocked by well-intentioned but entrenched bureaucracies and organizational structures whose own inertia and desire for self-protection and comfort slows the journey. A significant discontinuity between technology and its employment can be the catalyst that advances the progression to a revolutionary state. That catalyst for the strategic air campaign of 2010 is disproportionality.

The lack of a peer competitor today places the United States in the enviable position of unquestioned military superiority worldwide. Examining the defense budget expenditures of other countries also supports this fact. The US military spending greatly exceeds that of any other potential future peer competitor and also is greater than the next eight countries' defense budgets combined.[11] This resource advantage not only supports military superiority today, but will support orders-of-magnitude greater research and development funding in the future. The United States cannot only overwhelm any adversary with disproportional combat power in the field, but it also has the ability to maintain and expand its technology lead into the future.

Competing European powers have waged economic and military warfare against each other since the discovery of the New World. England, France, Germany, and Russia battled as the peer competitors at first. The nineteenth century added the United States as a global competitor. Today the end of World War II and especially the end of the cold war in 1991 has left the United States as the single remaining superpower. While this status will eventually change, for the near future the United States has the economic and military power advantages that, in concert, permit the disproportional application of national power globally. Disproportionality, tied with the synergy of doctrine, operational capabilities, organizational structures, and technology, has the potential to produce a strategic air campaign in 2010.

**Notes**

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## Chapter 2

# Doctrine for Strategic Air Campaigns

> *At the very heart of warfare lies doctrine. It represents the central beliefs for waging war in order to achieve victory. Doctrine is of the mind, a network of faith and knowledge reinforced by experience, which lays the pattern of the utilization of men, equipment and tactics. It is the building material for strategy. It is fundamental to sound judgment.*
>
> —Gen Curtis E. LeMay

Airpower pioneers such as Giulio Douhet, William "Billy" Mitchell, Henry Harley "Hap" Arnold, Ira Clarence Eaker, and John Warden have long espoused the doctrine that aircraft can overfly two-dimensional obstacles. Their doctrine stated that airpower would overcome the enemy's air defenses, strike directly at vital centers in the enemy's heartland, and accomplish strategic, war-winning objectives.[1] Prior to Desert Storm, proving this airpower doctrine correct had been difficult and costly. Historical evidence from World War II shows—through high-altitude, unescorted US daylight bomber raids against Germany (1942–44)—that a robust air defense can prove a formidable threat to bomber aircraft and the validity of a strategic air campaign. The German air defenses inflicted significant losses on US offensive airpower and forced the United States to make operational structure changes. In spite of these operational setbacks, the basic strategy was proved sound—that Allied airpower was decisive in Germany and Japan during World War II.[2]

The decisiveness of the strategic air campaigns against Germany and Japan was significant enough to support the formation of a separate air force distinct from and equal to the Army and Navy as a separate service. Since the end of World War II and the onset of nuclear deterrence, the development of airpower doctrine has stagnated.[3] Until the Persian Gulf War, AirLand Battle had been the primary focus of USAF conventional doctrine, and some identified this operational concept as the basic airpower doctrine rather than as an operational-doctrine concept. This operational concept, while effective at supporting ground forces, limits the strategic air campaign's fundamental breadth, depth, timeliness, scope, and ability to impact national objectives. The strategic air campaign doctrine of *JV2010* must emerge from the limitations of AirLand Battle thinking. A first step was provided by the strategic air campaign's decisive success of Desert Storm.[4]

As any employer of combat airpower learns, knowing one's own capabilities is as important as knowing the enemy's. The doctrinal concepts we value today are being linked to the operational concepts and organizational structures for JV2010. Today's weapons systems and technological capabilities will be phased out and replaced eventually. Our challenge is to link new technologies with our doctrine, operational concepts, and organizations. How we fight tomorrow depends on how we think today.[5]

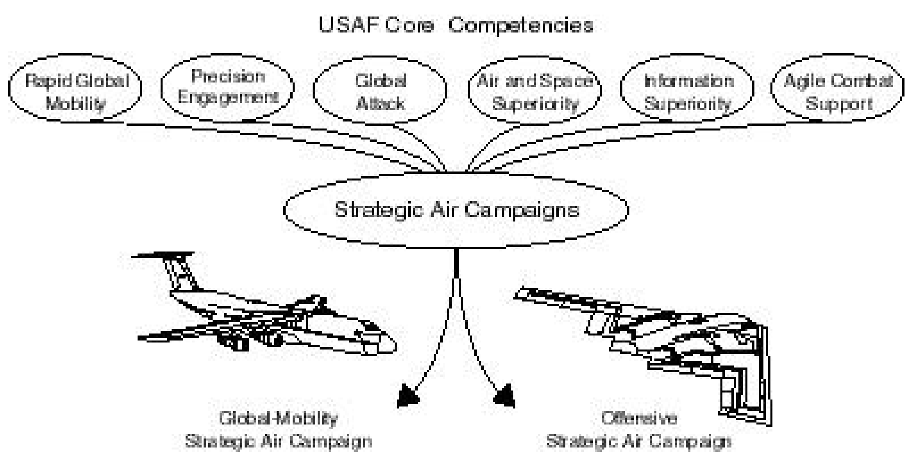


**Figure 2. Core Competencies Merge to Form Strategic Air Campaigns**

## Offensive Strategic Air Campaigns

Strategic air doctrine for *JV2010* is a distillation of the timeless concepts of our airpower pioneers. Today, that doctrine says that speed, range, freedom of maneuver, and perspective can employ national power globally via critical logistics or precision-weapons delivery.[6] US vital national interests will require the USAF to operate at long distances from the continental United States (CONUS) and the few available theater bases. The long-range staging may continue for weeks or months until sufficient theater forces can be bedded down.[7] JV2010 airpower will deliver disproportionately very large numbers of highly accurate weapons against the most critical and parallel enemy target sets in a rapid or near-simultaneous time frame. The resulting direct physical destruction and psychological shock will synergistically destroy the adversary's war-making abilities and reduce him to sufficiently marginal levels that follow-up operations will easily complete the overall military campaign's goals. The indirect nature of such an air attack may produce long-lasting changes to the enemy's warfighting and material production plans. These may be altered to divert forces and war production away from offensive victory initiatives towards increased air defense requirements.[8] The ferocity, rapidity, destructiveness, and disproportionality of attacks against parallel target sets by a US-led strategic air campaign, to the exclusion of an adversary to match it in return or successfully defend against it, is an RMA.

Realizing the war-winning and decisive goals of a US-led strategic air campaign will come as a result of having achieved direct and indirect effects against an adversary's leadership, command and control ($C^2$), military forces, industrial capacity, national infrastructure, and national and military plans. Such a strategic air campaign cannot be solely and simply defined via linear mathematics or quantitative analysis.[9] The decisive nature of any military campaign is its ability to effect a "state change" in the ability of the enemy to adapt to the attack. Once the threshold of such a change is reached and maintained, the adversary will be unable to stop the collapse of his system.[10] Exactly determining "how much" and "how long" military operations will take to reach this threshold is not knowable. However, the ferocity, rapidity, destructiveness, and disproportionality of attacks against parallel target sets by a US-led strategic air campaign beyond which an adversary can adapt is the essence of winning wars.

A strategic air campaign RMA requires that the United States be willing to fund, develop, train, and employ a military with an offensive global-reach capability that far exceeds the national capability of that of any of our adversaries.[11] Four key technologies are emerging that will permit us to project power easily, a key factor in realizing the revolutionary impact of a JV2010 strategic air campaign. These technologies are information, $C^2$, penetration, and precision.[12]

Information advances at the strategic level will provide better intelligence on the vital centers, structures, and centers of gravity of enemy power. $C^2$ will use information filtered and fused as dominant battle-space knowledge.[13] Using this knowledge, the commander can rapidly plan and execute the air campaign to strike those centers of enemy power and quickly react to the results. The low-observable technology linked with precision-guided missile/munitions (PGM) provides our military with revolutionary abilities to penetrate enemy airspace and strike those vital centers of gravity. Successful strategic air campaign penetration of enemy airspace is based on localized air superiority produced by the penetrator's stealthy signature. Flexible employment of PGMs, with overwhelming and disproportionate mass, will deny the enemy use of many of his vital centers of national power. Employing these technologies—broad in target scope, compressed in time, and with disproportionately, devastating mass and accuracy—will paralyze the enemy's leadership and defensive reaction. To fully optimize the airpower doctrine, strategic air campaigns must be planned to expect in-flight modification/adaptation of execution parameters while still achieving broad mission and campaign objectives. Using these new technologies to conduct a parallel war to simultaneously attack enemy centers of gravity will require equally innovative advances in organizational structures to realize the RMA promise/potential in such a strategic air campaign.[14]

## Global-Mobility Strategic Air Campaigns

While employing national combat power is the armed forces' core role, the United States, as the world's single superpower, has national interests that must be met by a strategic air campaign providing rapid global-mobility-delivering deterrence/peacekeeping forces, humanitarian supplies, assistance to disaster victims or domestic authorities, or key technologies. Today's multipolar world is more dynamic and requires that the United States, in its leadership role, respond with global mobility to crises worldwide. A global-mobility strategic air campaign supports national objectives by delivering the majority of time-critical forces and supplies.[15] Global mobility will require that peacetime operations may overfly former en route locations, maintain a high operations tempo, compete with normal airlift and air refueling requirements, and operate in hostile areas.[16]

The air expeditionary force (AEF) is designed to rapidly deploy worldwide and can be tailored to meet the needs of the joint force commander for military or nonmilitary operations.[17] The AEF, tailored as a combat force, provides a deterrent to regional aggression, demonstrating the United States's global reach and power. Another role for the AEF, tailored for lift and sustainment, would be to operate in a region for a period of time, replacing, augmenting, or providing a transportation infrastructure to deliver key logistics and resources to meet a regional humanitarian crisis. Global mobility can lift critical supplies and equipment that are hazardous, too large for civilian aircraft, or so time-critical to the war fighter that they can not wait for surface transportation.[18]

Prime historical examples of a global-mobility strategic air campaign are the Berlin airlift in 1948 and the resupply of Israel during the Yom Kippur War in 1973.[19] A more recent example of a global-mobility strategic air campaign's achieving national objectives was Operation Sapphire, during which the USAF C-5 transport aircraft rapidly and safely moved large quantities of weapons-grade nuclear fuel to US control and the transport of water purification equipment to save hundreds of thousands of Central African refugees from disease and death.

**Notes**

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Chapter 3

# Organizational Structures for Strategic Air Campaigns

The joint force air component commander (JFACC) will plan and execute the strategic air campaign. Planning and executing an offensive strategic air campaign requires an organizational structure that can rapidly gather all source information and fuse it into intelligence, develop strike plans, task operational units, and execute the missions. Real and near-real-time information gathering, fusion, and timely and accurate intelligence production are critical factors in a successful strategic air campaign. The "bandwidth" or size of the electronic pipe needed to transfer the large information and intelligence-data volumes potentially required by a regional JFACC to run an offensive strategic air campaign can exceed the communication and data-connectivity resources available to the war fighter now and possibly well into the future. This limitation on intelligence and communication may suggest that a strategic air campaign's early stage, across the spectrum of conflict in either logistical or combat operations, should be planned and executed from the United States.

At least the initial stages of a long-range strategic air campaign may well be best planned and executed by the JFACC located in the CONUS. The CONUS JFACC has many resource advantages: access to limited aerospace strategists, exercised connectivity with logistic and combat mission planners, all-source intelligence, and databases for combat units. A CONUS-located JFACC removes a fixed, in-range, high-value theater target for enemy counterstrikes or terrorism. The increased access to rapid information flow in future conflicts presents opportunities to the operational commander. Rapid decisions can be made on resource options, timing, targeting, and weapon choices. Potentially, the commander may be able to move his decision loop faster, making our forces more efficient and effective, while forcing on the opponent errors based on old information decisions.[1]

The global-mobility strategic air campaign requires a centralized command and control to support airlift and air refueling operations worldwide. A centralized control and execution system must provide a flexible, responsive, secure, survivable, integrated global information system.[2] Such a system provides the force-management decision makers the two-way connectivity and flexibility to reroute critical aircraft or resources, rapidly establish en route stations, or support operations in austere environments.[3]

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Chapter 4

# Operational Concepts for Strategic Air Campaigns

*Today's planners will develop the operational concepts for a 2010 war; how US aerospace forces fight tomorrow will be guided by how US aerospace planners think today.*

—Col Jeffrey Barnett
*Future War*, January 1996

*JV2010* provides broad new operational concepts, dominant maneuver, precision engagement, full-dimensional protection, and focused logistics.[1] Focused logistics, dominant maneuver, and precision engagement are the concepts that most readily lend themselves to the JV2010 strategic air campaign design. Long-range precision capability to deliver critical resources, combat power, or weapons on target is the primary synthesis of these operational concepts for future strategic air campaigns.

## Operational Concepts for Offensive Strategic Air Campaigns

Stealth aircraft are a key for airpower to penetrate defended airspace and achieve strategic and operational campaign objectives. Stealth or low-observable penetrating (LOP) aircraft have unique doctrinal capabilities, attributes, and operational requirements. Effective strategic air campaign design must be based on the doctrine and employment concepts that LO aircraft offer. Understanding the strategic air campaign RMA requires a discussion of these proposed LO-operational concepts.

### Low-Observable Penetrators

Low-observable penetrators have a high probability of penetrating enemy airspace by providing their own local air superiority. The LOP's most significant doctrinal capability is its very high probability to penetrate successfully an adversary's air defense net and accurately deliver logistical resources or weapons without large-scale, expensive support from other aircraft, such as fighter escort or electronic-warfare aircraft. This ability is based on revolutionary low-observable technology and a dramatically reduced LO-aircraft signature. Maintaining the LO signature is, therefore, a high priority to successfully employ these aircraft. Maintaining the LO signature includes mission planning, tactical employment of the aircraft, and aircrew training. The LO-employment doctrine may call for mission planning and execution flexibility in routing, mission timing, and target prioritization. The product of LO technology and flexible employment allows LOPs to exercise passive air superiority. This passive air superiority is revolutionary for offensive aircraft and realizes the long-held visionary doctrine of Giulio Douhet and Billy Mitchell on "command of the air" and the survivability of penetrating aircraft to counterdefenses.[2]

The LOP gains its revolutionary advantages from the low probability that enemy defenses will be able to detect and successfully perform an intercept. While the LOP is not invisible to defense sensors, its stealth characteristics allow it to break the engagement hierarchy: detection, correlation, tracking, weapon guidance, and warhead fusing. Any break in this sequence of events will allow the LOP to survive, escape, and/or recloak to an undetected status and continue the mission. Some of the major sources of signature detection are active search by radar, passive detection of the infrared and acoustic emissions of an aircraft's engine, visual detection of the aircraft (shape, shadow, color, or contrail), and passive detection of an aircraft's self-generated emissions (radar, radio, or navigation aids).[3] Maintaining an LO signature depends on the design, construction, and aircraft maintenance quality as well as on smart mission planning and in-flight tactics.

### Active Signature Management

LOPs must have autonomy of action and mission execution flexibility to preserve stealth advantage by active signature management. The ability to penetrate air defense systems successfully and deliver key logistic resources or weapons requires that LOP signature management have a high mission priority. Dominant battle-space knowledge of threat-systems numbers, locations, and abilities will factor into mission planning. During the flight phase, mission updates from off- and/or onboard sensors may require that the route of flight, timing, target, and weapon selection be changed for LOP signature management. This level of autonomy of action and flexibility in mission execution is key to the effectiveness of a JV2010 strategic air campaign.

Tactical surprise, deception, situation awareness (SA), combat judgment, and aircrew initiative are critical skills to mission success. The choice of employment tactics will determine whether the LOP is to be used as either an evolutionary or a revolutionary weapons system. Evolutionary employment would occur where stealth technology is simply used to decrease the detectability of a penetrating aircraft. Revolutionary employment would consist of flexible mission parameters that allow the aircrew to combine innovative penetration tactics and stealth technology to provide a significantly more effective weapons delivery platform. The tactical philosophy for a low-observable penetrator has four basic tenets as follows:

1. Avoid detection.
2. If detected, evade and escape.
3. If engaged, survive.
4. Recloak to an undetected status.

## Threat-System Detection

Low-observable penetrators will detect and identify active air defense systems before those systems can detect the penetrators. The high priority of signature management and the means to achieve it, using autonomy of action and mission-execution flexibility, is based on this ability to see and counter threats before you are seen. The reduced signature of LOPs will degrade the ability of an air defense's command and control system to easily identify the flight path, route timing, and intended targets. Knowing that an attacking force is probably penetrating its airspace, yet unable to identify when, where, or what targets are threatened, can fracture the defensive $C^2$ network and make it more susceptible to deception, disruption, and paralysis.

## Revolutionary Employment of LOPs

Revolutionary employment of LOPs requires dominant battle-space knowledge. JV2010 strategic air campaigns must heed Sun Tzu's advice: "Know your enemy and know yourself, in a hundred battles you will never be in peril."[4] To achieve LOP-employment success, mission planning must support signature-management priority, high mission-planning effectiveness, in-flight SA, and combat-judgment skills. Effective mission planning prepares the aircrew for the best routing, expected defensive order of battle, and mission objectives. Once the battle begins, however, the fog and friction of war will make these best-laid plans nothing more than a place from which to make changes. Situation awareness and combat judgment are the key in-flight skills LOP aircrews must use to make those smart changes and take maximum advantage of their stealth technology.[5] Aircrews must observe, orient, decide, and act during penetration flight profiles. Just as our LO doctrine is based on airpower flexibility, the enemy cannot be expected to follow a set list of actions.[6] The LOP aircrew must use dominant battle-space knowledge to build and maintain SA and make smart combat judgments to take advantage of the tactical situation. The LOP aircrew must use these skills to maintain their LO signature and, if detected, break the engagement hierarchy to escape, survive, and recloak.

## LOP Passive Attack

LOPs inflict a "passive attack" to deceive and confuse enemy command and control systems, which are the center of gravity of the enemy's air defenses. LOPs can passively provide their own local air superiority by minimizing detection and breaking the engagement sequence early. Successful LOP employment will degrade defensive $C^2$ nets. While air defense technology will continue to advance, a radar system that would be capable of detecting and tracking stealth aircraft would require a computational and data-fusion ability several orders of magnitude greater than any that exists today.[7] Today, no contemporary air defense system can detect and intercept a strike force of LOPs.[8] Air defense forces may be depleted in unsuccessful searches and intercept attempts. LOPs can choose to unmask their aircraft intentionally or use uninhabited air vehicles to intentionally decoy air defenses, then recloak and leave interceptors out of position, degrading further defensive action. These LO deception-employment doctrines can be phrased as a passive attack. An air defense system would have significant difficulty correlating numerous spurious-position and track-information inputs. A $C^2$ center subject to confusion and disruption could misallocate interception assets. The LO passive attack is a weapon whose antiweapons impose the greatest possible strain on the production facilities and military efforts of the opponent.[9]

### Nighttime Employment Is a Force Multiplier

While LOPs have the potential for all-weather employment, the threat to the visual portion of their detectable signature is so increased that daytime missions should be greatly restricted and used only when the threat is very low or the national need is great. Penetration of air defense at night balances signature-management concerns, aids surprise, enhances deception efforts, and degrades interception.

## Operational Concepts for Global-Mobility Strategic Air Campaigns

*The single biggest deficiency in the Department of Defense is lift.*

—Gen Ronald R. Fogleman, CSAF
Address to *JV2025* Participants

Long-range transport aircraft must increasingly operate from the CONUS to rapidly project power that establishes or reinforces US or multinational regional presence. *JV2010*'s Focused Logistics and *Global Engagement*'s Rapid Global Mobility and Agile Combat Support require operational concepts that can deliver critical resources to worldwide locations, some of which are very austere.

### Precision Airdrop

Precision airdrop is the most rapid means to deliver equipment, resources, and personnel anywhere. Airdrop transports troops and material from an aircraft in-flight when the air-land option is not available and an immediate response is required. Many forced-entry operations require airdrop. Some peacetime operations in remote areas require airdrop to meet timelines or to deliver equipment that can prepare airfields for air-land operations.[10]

### Air Refueling

Air refueling permits rapid deployment of national military power or humanitarian resources without the requirement for staging bases. Tanker aircraft supports the rapid deployment of combat and transport aircraft to achieve national objectives. This force-projection capability decreases reliance on intermediate stops at refueling or staging bases that may be increasingly denied to us or if time requirements force a direct delivery. Air refueling increases payload capacity by minimizing take-off fuel loads that decrease available cargo weight. Combat operations require air refueling to increase sortie duration and range that permit staging high-cost assets at safe airfields and multiplying the available combat power applied on target.[11]

### Delivery of Critical Resources

Airlift delivers critical resources and personnel that achieve national objectives to help our allies and friends when assisting people, relieving crises, deterring aggression, and winning battles. Global airlift delivers supplies, equipment, and personnel that cannot wait for surface transportation modes. Our national security strategy of defense, engaging our friends and potential adversaries, and supporting democracies around the world is directly supported by airlift. USAF airlift assets are specifically designed to meet the toughest requirements such as transporting outsized cargo or special items to austere locations. Airlift supports special operations for covert or overt NCA missions.[12]

LO and PGM technology and timely, accurate logistics delivery meld classic airpower doctrine of Douhet and Mitchell with the unique attributes of stealth penetrators' high probability to penetrate, autonomy of action, mission-execution flexibility, and signature-management flexibility, striking vital centers massively, rapidly, and destructively. Disproportionality and parallel war are prime factors in successful deterrence and early conflict resolution. Strategic air campaigns provide this potential without the costly requirement to mass ground forces in close combat as the prime military coercive force. LOPs, paired with PGMs and global-mobility systems, have reenergized the discussion on the value of strategic air campaigns to meet national security and military strategy objectives.

**Notes**

1. Gen John M. Shalikashvili, chairman of the Joint Chiefs of Staff, *Joint Vision 2010* (Washington, D.C.: Office of the Chairman, July 1996), 19.

2. Giulio Douhet, *The Command of the Air* (New York: Coward-McCann, 1942); and Alfred F. Hurley, *Billy Mitchell, Crusader for Air Power* (Bloomington, Ind.: Indiana University Press, 1975).

3. Bill Sweetman, *Stealth Aircraft* (Osceola, Mich.: Motorbooks International, 1986), 58.

4. Sun Tzu, *The Art of War,* trans. and introduction by Samuel B. Griffith (England: Oxford University Press, 1963), 84.

5. Robert L. Shaw, *Fighter Combat, Tactics, and Maneuvering* (Annapolis, Md.: Naval Institute Press, 1987), 291.

6. Gen Larry D. Welch, commander in chief, Strategic Air Command, comment on SAC's mid-1980's Aircrew Tactical Doctrine.

7. *Discriminate Deterrence* (Washington, D.C.: Commission on Integrated Long-term Strategy, January 1988), 41.

8. Thomas A. Kearney and Eliot A. Cohen, *Gulf War Air Power Summary Report* (Washington, D.C.: USAF, 1993), 224.

9. Oskar Moreganstern, *The Question of National Defense* (New York: Random House, 1959), 22.

10. *1997 Air Mobility Master Plan* (Scott AFB, Ill.: Headquarters Air Mobility Command, October 1996), 1–10.

11. Ibid., 1–11.

12. Ibid., 1–13.

Chapter 5

# Technology for Strategic Air Campaigns

> *Because of earlier investments, particularly in technologies, our military capability is improving rapidly, and these improvements point toward a qualitative jump in our ability to use military force effectively. We will be the first nation to pass through the revolution, emerging with different strengths that can give us an edge across the entire spectrum of contingencies against which the nation may need to commit its military.*
>
> —Adm William A. Owens
> *High Seas*, 1995

New tools of war have limited impact on the way of war without corresponding modifications in doctrine, operational concepts, and supporting organizational structures. A brief example is the impact of the new tank technology on pre-World War II German and French military organizations. The Germans developed doctrine and employment concepts (i.e., blitzkrieg) and supporting organizational structures (i.e., panzer division in a combined arms corps) that made them victorious through 1942 on the Eastern and Western Fronts. The French employed their tank technology in existing infantry units with little employment changes and suffered rapid defeat.[1]

The technology environment for a JV2010 offensive and global-mobility strategic air campaign will have significant improvements in reconnaissance, communications, data-transfer rates and volume, information production, LO aircraft with penetration-enhancing electronic-warfare systems, accurate navigation and delivery systems, and PGM with all-weather and automatic target-recognition capabilities.[2]

## Technology for Offensive Strategic Air Campaigns

Low-observability technology applied to aircraft design and on-board electronic-warfare penetration aids will severely limit the ability of enemy air defenses to detect, neutralize, and intercept our attacking aircraft. Thus, the enemy's most highly valued and critical targets will become vulnerable to our offensive airpower.

Successful strategic air campaigns in the arena of tough integrated air defense systems are dependent on stealthy or low-observable aircraft. Stealth technology, accurate delivery techniques, and PGMs, when applied to the design of a combat aircraft, will result in weapons systems that can maintain deterrence well into the future and, if needed, will allow the United States to employ combat power anywhere in the world. As with any new technology, the military must develop and constantly refine effective operational concepts, organizational structures, and doctrine to put these technological advances to their best use. The air campaign planner employing LOPs with critical resources or PGMs must understand LO doctrine, technology, and how these weapons systems penetrate/counter the enemy's defensive systems, deliver focused logistics, or strike targets. Learning the employment fundamentals is critical to effective offensive strategic air campaigns. Additional detailed information on LO technology is available in appendix A.

LO allows us to finally achieve the long-held doctrinal beliefs that the "bombers will get through" and strike strategic targets. Strong enemy defenses have caused airpower strategists to give more weight to supporting penetration aspects of a mission than to offensive initiative and freedom of action in making operational and tactical employment decisions. Decisions about ingress points, penetration routing, routing corridor width, timing constraints, and weapon load versus penetration aids are examples of how the defense has limited offensive initiative and freedom of action. The ability to limit detection and degrade interception to acceptably low levels allows LOPs to slip through gaps in air defense systems. Simply stated, the LOP has the potential to enter hostile airspace, strike targets, and survive to fly again. The impact of this airpower doctrinal belief on strategic air campaigns is enormous. The challenge for airpower employers will be to merge these LO doctrinal beliefs with the inherent potential of airpower for expansive flexibility.

## Technology for Global-Mobility Strategic Air Campaigns

Global-mobility strategic air campaigns also require superior technologies. Long-range transport aircraft should be dual-roled to provide both airlift and air refueling capability. High levels of reliability are an increasing technology requirement to match operating tempos with decreasing aircraft resources and availability. Precision navigation and redundant communication electronics are required to operate in austere environments and to enhance true worldwide mission flexibility. Future airlift aircraft should have the following characteristics:

1. Reliable, cost-effective delivery of large cargo payloads over long distances using air refueling support.
2. Direct worldwide delivery from the CONUS to austere environments.
3. Delivery of outsized cargo that cannot be carried by commercial technology.
4. Roll-on and roll-off capability.
5. Routine low-threat-environment survivability.
6. All-weather airdrop and air-land operations.[3]

Air refueling also is a fundamental part of a global-mobility strategic air campaign. Transport aircraft configured in a tanker role should have the following capabilities:

1. Refuel the entire range of US and allied aircraft.
2. Support very large offensive strategic air campaigns such as the single integrated operational plan (SIOP) or Desert Storm.
3. Survive in a wartime threat environment.
4. Provide large fuel offload with maximum flexibility.[4]

Future mobility aircraft can also benefit from advanced technologies available today or that are linked to a JV2010 vision. Low-observable technology applied to unmanned aerial vehicle (UAV) airlift or refueling aircraft could greatly decrease their radar cross sections by eliminating the cockpit. Very high speed aircraft operating at supersonic or hypersonic speeds could efficiently deliver critical logistics or personnel around the world within minutes. Very large aircraft with gross weights exceeding one million pounds would increase the efficiencies of airlifters up to 1.5 times our capabilities today.[5]

Technology superiority can be a tenuous advantage. Advances in science and engineering applications are seldom kept secret for long. The US military should expect advanced application and exploitation of our technology and new ideas to emerge worldwide. Keeping our technology superiority requires large, diverse, and continuing investment in new concepts. Equally important is investing in our own counter-US technology effort. We should fund research into those defense technologies that have the potential to defeat our information gathering, $C^2$ connectivity, penetration, and target vulnerability abilities. Recognizing our vulnerabilities before our enemies or potential competitors do is an important factor in enhancing our deterrence and war-fighting abilities.

Technology is an equal contributor in pursuit of a strategic air campaign RMA. We perceive that the quality of technology, that is, innovative ideas employed to achieve military objectives, is its important single benefit. In a single-superpower world where the US military budgets far exceed the combined financial outlays of many of the next largest country's military expenditures, "technology mass" is a new emerging factor. The ability to outspend our nearest competitors by several orders of magnitude in technology development, weapons procurement, leading-edge operational conceptual development, and realistic training will give the United States a lasting military superiority in both deterrence and war winning; this is the fundamental disproportionality concept.[6]

Projecting global power across the spectrum of conflict via global-mobility or offensive strategic air campaigns and military superiority has very real limitations and does not guarantee or imply US world dominance. The United States remains very much dependent on our allies and on crisis coalitions for legitimacy and assistance. The United States will seldom employ military power unilaterally. We rely on our allies and "situational friends" for political and financial support. While the United States is clearly the world's superpower, political and economic power will continue to reign as the chief tools of the combined nation's power on the world stage.[7]

## Notes

1. Jeffrey Record, "Force Projection/Crisis Response," *Turning Point: The Gulf War and US Military Strategy,* ed. Benjamin Ederington and Michael J. Mazarr (Boulder: Westview Press, 1994), 14–15.

2. Ibid., 27.

3. *1997 Air Mobility Master Plan* (Scott AFB, Ill.: Headquarters Air Mobility Command, October 1996), 1–30.

4. Ibid., 1–31.

5. *Airlift 2025: The First with the Most* (Maxwell AFB, Ala.: 2025 Support Office, Air University, August 1996).

6. Dr. David Blair, *How to Defeat the US: The Operational Military Effects of the Proliferation of Weapons of Precise Destruction* (Maxwell AFB, Ala.: Air War College, January 1996).

7. William J. Taylor and Michael J. Mazarr, *North Korea and the Gulf War* (Washington, D.C.: Center for Strategic and International Studies, November 1991).

# Epilogue

As we implement the chairman's vision via service core competencies, as those expressed in the US Air Force's *Global Engagement*, we will attain a new airpower-employment synthesis. The new synthesis will blend airpower doctrine; new operational capabilities; high-operational-tempo organizational structures; and high-penetration, low-observable, and long-range aircraft technology to deliver critical resources or employ precision weapons rapidly and disproportionately against a parallel set of targets. This tool of national military power gives the JFC and the NCA a global-mobility or offensive strategic air campaign, in peace and war, with decisive capabilities across the spectrum of conflict.

The direct and indirect nature of such an offensive strategic air campaign may produce long-lasting changes to the enemy's ability or will to continue the fight. The combination of the air campaign's doctrine, operational capability, organizational structure, and technology has the decisive ability to effect a "state change" in the enemy's ability to react or adapt. Once this state-change threshold is achieved, the adversary's war-fighting ability will fail, and our national objectives can be achieved.

Global-mobility strategic air campaigns can also achieve national objectives by the timely and precise delivery of key logistical support and resources to aid our allies, friends, and humanitarian efforts around the world in pursuit of the engagement and enlargement of national security strategy. The Berlin airlift and logistical support to Israel during the Yom Kippur War are clear examples that peacetime strategic air campaigns can decisively achieve national objectives. This is equally true for the global-mobility strategic air campaign. Precise, timely delivery of critical resources worldwide can prevent humanitarian crises from escalating into a conflict or be the enabling action that permits US national power and influence to achieve combined and coalition goals. Global-mobility strategic air campaigns provide a strong deterrent—timely, accurate power projection worldwide.[1]

The conflict between the concepts of future strategic air campaigns as revolutionary or evolutionary is complex and can be argued persuasively for either position. The combination of an RMA's four components alone may be perceived as advancing technology leading doctrine, capabilities, and organizations. Just as the reality of an RMA is not decided solely by new technology, so the value of any national-power tool must be tested and proved in the world's political, economic, and military environments. Hence, the addition of disproportionality to the discussion, provided by quantitatively and qualitatively vastly superior US military power, must then throw the decision to the revolutionary side. As we complete this RMA-component synthesis of service core competencies employed by the joint force commander, the United States will be the first nation to experience a revolution in military affairs via a strategic air campaign (fig. 3).


**Figure 3. Strategic Air Campaigns Applied Disproportionally Result in an RMA**

**Notes**

1. *1997 Air Mobility Master Plan* (Scott AFB, Ill.: Headquarters Air Mobility Command, October 1996), 1–33.

# Appendix A

# The Theory of Low-Observable Technology and Penetrator Aircraft Design

Strategic air campaigns using LO aircraft require commanders, planners, and aircrews who can effectively design and execute missions. These operators must understand LO doctrinal concepts, tactics, techniques, and procedures. This appendix provides a small introduction to this area for those readers interested in more detailed information.

Aircraft can be detected by active radars, infrared detectors, human visual observation, acoustic "ears" (i.e., both human and electronic), and sensors that detect aircraft-generated radio, radar, and other telltale electronic emissions. LO technology permits aircraft designers to build aircraft that are hard to locate and intercept; that is, they have small "signatures." The signature (fig. 4) of an aircraft consists of those specific clues that betray its presence and may even identify its specific type. To make an aircraft truly LO, the design of the aircraft must minimize possible sources of detection and emissions, and future means of detection must be anticipated. The commanders, planners, and aircrews who operate these aircraft must understand the design and construction as well as the employment doctrine and tactics if they are to effectively employ such advanced aircraft.

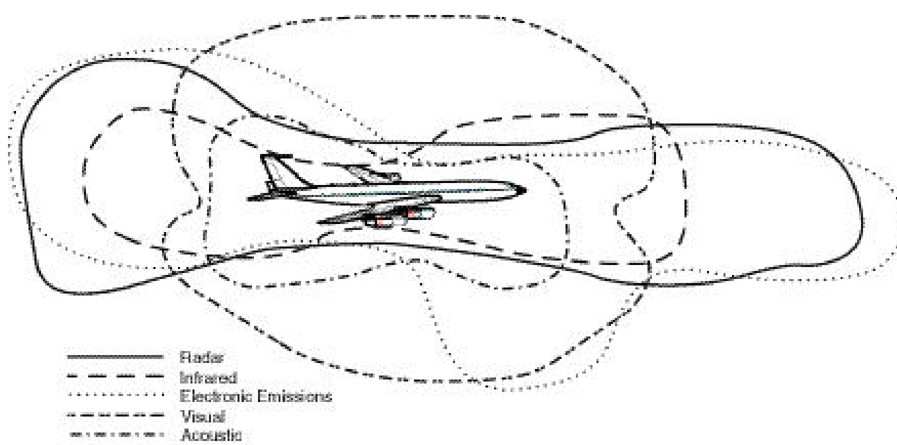
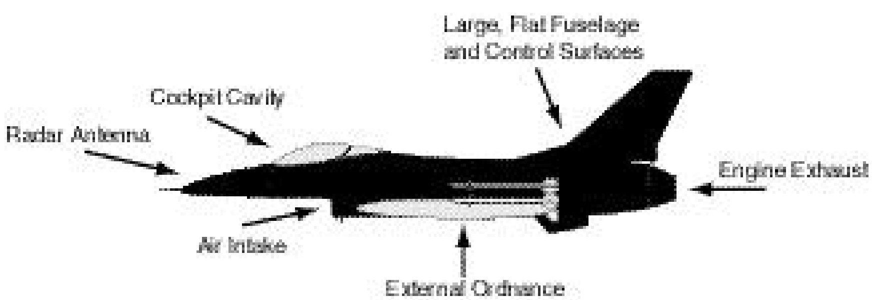



**Figure 4. Notional Detection Signature of a Typical Aircraft Design**

### The Hows and Whys of Aircraft Detection

Making an LO penetrator truly difficult to detect is an imposing technical and operational task. A look at the design of a typical aircraft (fig. 5) shows that conventional military aircraft produce complex and strong radar returns from the flat slab sides of the fuselage, wings, and control surfaces. The engine compressor and exhaust turbine are also excellent reflectors and produce very identifiable radar returns. An afterburning engine produces a strong source of infrared emissions for detection, tracking, and weapons guidance. Visual detection of aircraft is dependent on their size, color, and maneuvering tactics. Aircraft can also be readily detected by their own self-generated emissions from radio, radar, and navigation equipment. Noise, while not a major detection medium today, must be minimized when an LO aircraft is designed and operated. Reducing and then managing these readily detectable aircraft characteristics require not only major design changes, but also revolutionary new employment tactics.




**Source:** Doug Richardson, *Stealth: Deception, Evasion, and Concealment in the Air* (New York: Orion Books, 1989).

**Figure 5. Readily Detectable Characteristics of a Typical Combat Aircraft**

Radar was first used during World War II and has since become the primary method of detecting airborne targets. Radar has achieved its predominance because radar waves are not as easily affected by atmospheric conditions as are visible light waves; clouds and rain can block visible-spectrum light waves. Moreover, lower-frequency radar waves can bend around the horizon, thus increasing the range of detection of previously unseen targets. Radar also works at night when visual means of target detection are quite limited. Radar detection has another advantage over visual observation in that it provides its own source of illumination, whereas human vision depends on other light sources to illuminate objects (e.g., sun or bright moon). Radar is also very useful because it provides a ready means of determining the range, elevation, and azimuth to the desired target.

Military radars have different uses such as surveillance, long-range target acquisition, target tracking, and weapons guidance. A basic difference between these functions is the operational frequency of the radar. Low-frequency radars are used for long-range surveillance and acquisition. These radar antennas are necessarily large and therefore are normally in fixed facilities. Higher-frequency radars are used for target tracking and weapons guidance. These radars maintain high-quality target-position information such as angle, elevation, and range. These high-frequency radar antennas are smaller and can be mobile. Air defense networks use the basic target-position information to direct the interception and destruction of penetrating aircraft. Radars of all types can be based at sea, in the air, or on land and can detect targets in the midst of background clutter or electronic countermeasures. Radar frequencies fall between three megahertz (MHz) and three hundred gigahertz (GHz) on the electromagnetic spectrum (table 1).

Each radar band has specific uses, some of which are reserved for military use, others for civilian use (table 2). For example, the very high frequency (VHF) and ultra-high frequency (UHF) radars are used for surveillance, acquisition, and looking beyond the horizon. The target tracking radars operate in higher bands, commonly E through I bands. The highest radar frequencies are used for weapons fire control and missile seeker guidance.

Radar detects targets by transmitting electromagnetic energy waves and receiving a part of one of the energy waves after its reflection or scattering off the radar target. The size of the target with respect to how it reflects or scatters the incoming radar wave is a basic definition of *radar cross section* (RCS). The larger a target's RCS, the more incident radar en-

**Table 1**

**Radar Frequency Bands**

| STANDARD RADAR BANDS | | ELECTRONIC COUNTERMEASURE BANDS | |
|---|---|---|---|
| **Band Designation** | **Frequency Range (MHz)** | **Band Designation** | **Frequency Range (MHz)** |
| HF | 3–30 | A | 0–250 |
| VHF | 30–300 | B | 250–500 |
| | | C | 500–1,000 |
| UHF | 300–1,000 | D | 1,000–2,000 |
| | | E | 2,000–3,000 |
| L | 1,000–2,000 | F | 3,000–4,000 |
| S | 2,000–4,000 | G | 4,000–6,000 |
| | | H | 6,000–8,000 |
| C | 4,000–8,000 | I | 8,000–10K |
| X | 8,000–12K | J | 10K–20K |
| $K_U$ | 12K–18K | K | 20K–40K |
| | | L | 40K–60K |
| K | 18K–27K | M | 60K–100K |
| $K_A$ | 27K–40K | | |
| Millimeter | 40K–300K | | |

**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 16.

ergy it reflects back towards the transmitting site and, consequently, the easier the target is to detect by that radar receiver. Conversely, the smaller the target's RCS, the less energy it will redirect toward the "listening" radar receiver and the harder it will be to detect. Therefore, the primary factor in decreasing the detectability of an aircraft by radar is to reduce the RCS of that aircraft. RCS is expressed in terms of area and is measured in square meters ($m^2$) or decibel square meters (dBsm) (table 3).

The RCS of an aircraft can be difficult to predict and determine accurately and rigorously. The RCS of an aircraft depends on the physical design aspects of the aircraft (e.g., shape, size, or material); the transmitting frequency of the radar (e.g., 100 MHz or 10 GHz); the degree of polarization of the incident and reflected radar wave; the angular orientation

**Table 2**

**Radar Frequency Bands and Common Uses**

| BAND DESIGNATION | FREQUENCY RANGE | GENERAL USAGE |
|---|---|---|
| VHF | 50–300 MHz | Very Long Range Surveillance |
| UHF | 300–1,000 MHz | Very Long Range Surveillance |
| L | 1–2 GHz | Long-range Surveillance and En Route Traffic Control |
| S | 2–4 GHz | Moderate-range Surveillance and Terminal Traffic Control |
| C | 4–8 GHz | Long-range Tracking and Airborne Weather Detection |
| X | 8–12 GHz | Short-range Tracking, Missile Guidance, Mapping, Marine Radar, and Airborne Intercept |
| $K_U$ | 12–18 GHz | High-resolution Mapping and Satellite Altimetry |
| K | 18–27 GHz | Little used due to water vapor absorption |
| $K_A$ | 27–40 GHz | Very High Resolution Mapping and Airport Surveillance |
| Millimeter | 40–100+ GHz | Target Typing |

**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 17.

**Table 3**

**Relationship between RCS Measurements of Decibel Square Meters and Area Square Meters**

| Decibel Square Meters (dBsm) | Square Meters ($m^2$) |
|---|---|
| 50 dBsm | 100K $m^2$ (aircraft carrier) |
| 40 dBsm | 10K $m^2$ (frigate) |
| 30 dBsm | 1K $m^2$ (large transport aircraft) |
| 20 dBsm | 100 $m^2$ (bomber) |
| 10 dBsm | 10 $m^2$ (fighter) |
| 0 dBsm | 1 $m^2$ (cruise missile) |
| –10 dBsm | .1 $m^2$ (reduced signature aircraft) |
| –20 dBsm | .01 $m^2$ (large bird) |
| –30 dBsm | .001 $m^2$ (small bird) |
| –40 dBsm | .0001 $m^2$ (insect) |
| –50 dBsm | .00001 $m^2$ (?) |

of the target's physical dimensions compared to the incident radar wave (e.g., aspect or viewing angle) (fig. 6); and the mission profile of the aircraft (e.g., high-, medium-, or low-altitude profile).[1]

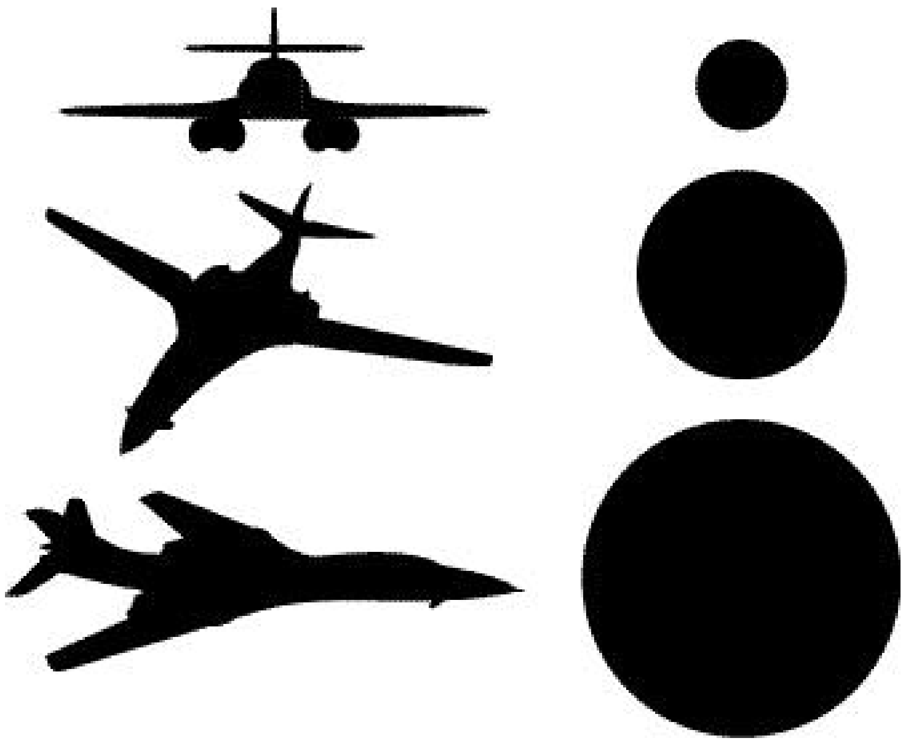


**Figure 6. Variations in RCS with Angle**

An aircraft does not present a single RCS value that remains constant for all situations or observation orientations. Early concepts of an aircraft radar return were regarded as a point source that reflected the radar energy uniformly back towards the transmitter; measuring the physical area of the target aircraft gave the aircraft's RCS expressed in square meters. This simple concept of RCS is useful for basic discussions, but the physics of RCS are more complex. Rotating the aircraft to expose different orientations—viewing or aspect angles—to the searching radar reveals that the RCS will vary with the aspect angle (fig. 7).

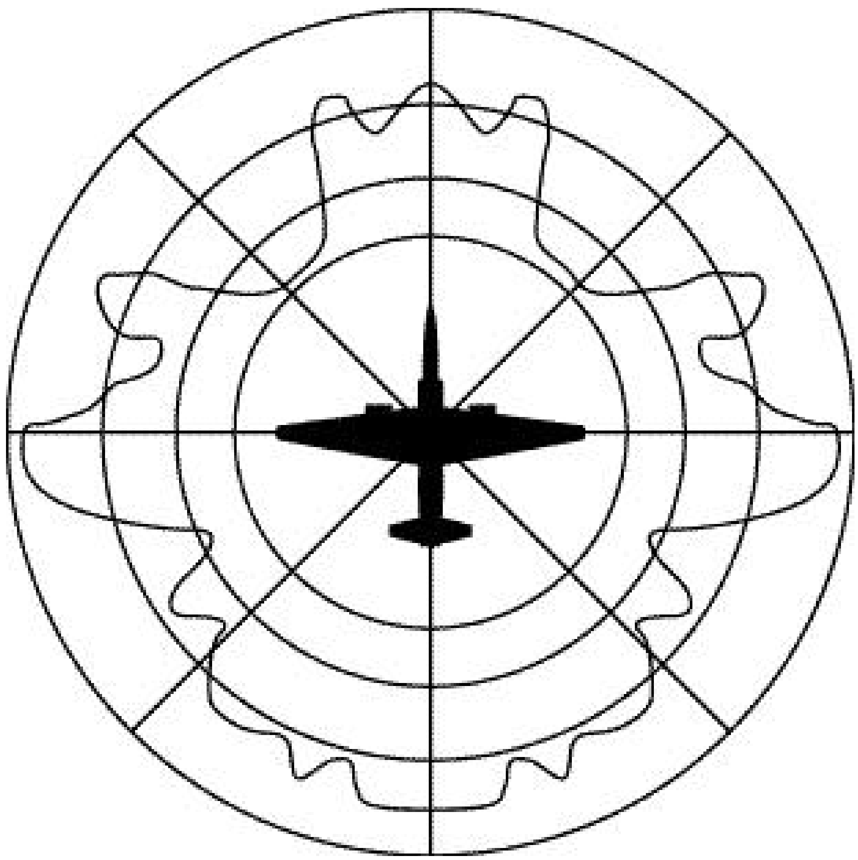
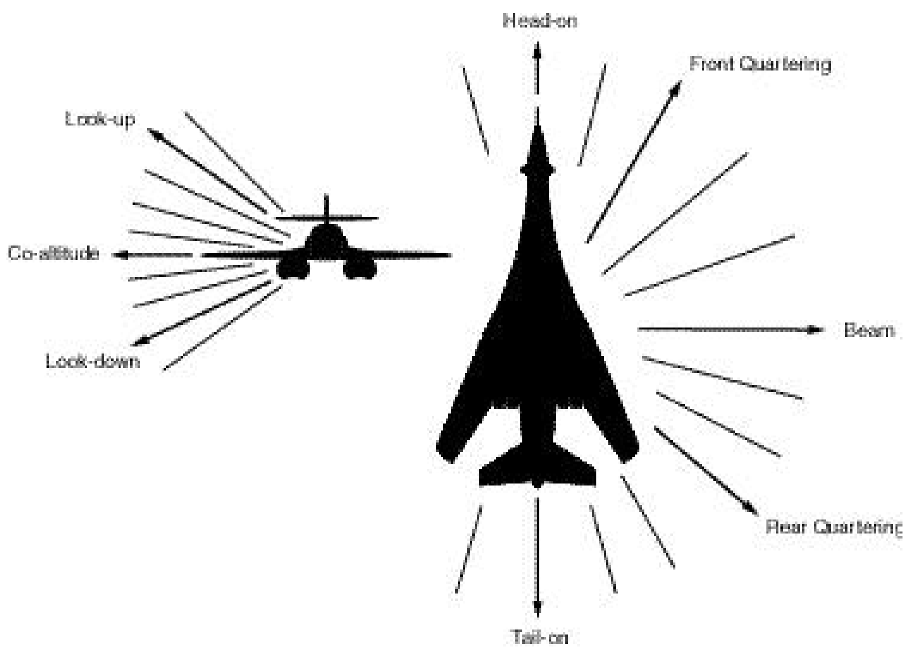


**Figure 7. All-Azimuth Plot of an Aircraft RCS**

Even this polar or all-azimuth plot oversimplifies the true picture of RCS for different azimuths. The radar returns will vary due to mutual-phase interference and polarization of the radar reflections. The value of RCS also changes, sometimes quite significantly, for succeeding radar pulses. The better solution is to express RCS in terms of the radar return's statistical parameters (e.g., mean value, percentiles, and probability densities). Moreover, as radar resolution improves, the radar engineer finds that a target is not just a point source of reflected energy; rather, it consists of a group of radar-scattering centers. This increased level of complexity produces RCS measured in terms of three-dimensional (i.e., azimuth and elevation) plots of grouped scattering centers, where RCS values are a function of the transmitted radar frequency, radar wave polarization, and viewed aspect angle of the target (fig. 8).



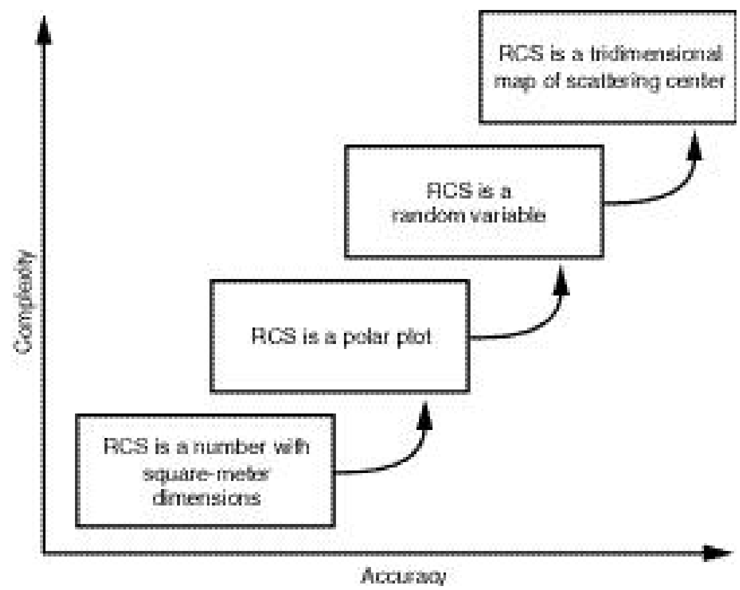

**Source:** *The Camouflage Handbook,* AAFWAL-TR-86-1028 (Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories, 1986), chap. 5, C-9.

**Figure 8. Three-Dimensional Viewing Angle Aspects and Geometries**

Aircraft produce complex RCSs. The complex returns are the result of many scattering centers: engine intakes, compressor/turbine blades, flat-wing pylons, and the right angles where the wing and the fuselage are joined. Small radar scatterers such as rivet heads and skin seams add to an aircraft's RCS. As the aircraft's orientation to the illumination radar changes, the strength of the RCS returns varies greatly and rapidly. The rapid RCS variation is termed *glint* and *scintillation*. Figure 7 shows how with a small change in viewing angle the intensity of the RCS increases rapidly. Figure 8 depicts viewing angles used to describe aircraft detection geometries.

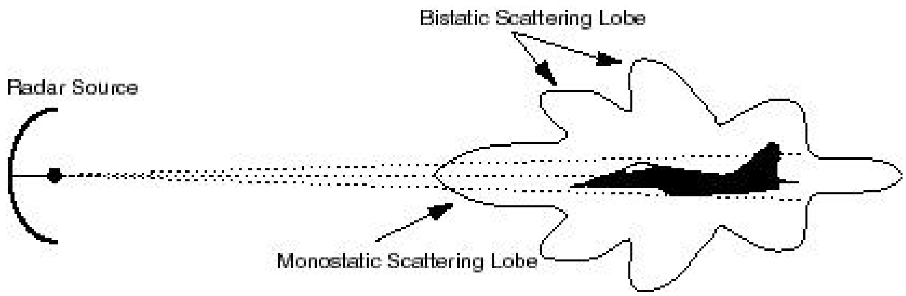
### Radar Cross Section and Scattering Fields

The RCS of an object or an aircraft results from the scattering of radar waves—the reflection, transmission, or diffraction of the incoming radar wave (fig. 9). The scattering that occurs depends on the shape, size, and material characteristics of the aircraft and the parameters of the incoming radar energy. The scattering angles or lobes of most concern to the LO aircraft designer are monostatic and bistatic scattering (fig. 10). Monostatic scattering and detection occurs when the radar wave is reflected directly back toward the collocated transmitter and receiver site. Bistatic scattering takes place when the incident-radar energy is scattered away from the transmitting




**Source:** *The Camouflage Handbook,* AAFWAL-TR-86-1028 (Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories, 1986), 69.

**Figure 9. Evolution of the RCS Concept**




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 52.

**Figure 10. Radar Wave Scattering**

source, the scattering angle is less than 180º, and any potential radar-reflection receiver is not collocated with the transmitter.

Basic radar wave scattering can be described as three frequency regions: the Rayleigh region, the resonant region, and the high-frequency region (table 4). Scattering can occur when the aircraft dimensions reradiate radar energy that has approximately the same dimension as the incident-radar wavelength. The Rayleigh region consists of radar energy wavelengths that are longer than the aircraft's physical dimensions of fuselage length and wing span (i.e., very low radar frequencies). The Rayleigh region may not contribute much to the observed RCS of most manned aircraft.[2]

Radar energy in the resonant region has wavelengths that are between .1 to 10 times the aircraft's dimensions; approximately the same size as the aircraft's wingspan, fuselage length, and engine configuration. In this frequency region, the shape, design, and material used in the aircraft does not ap-

**Table 4**

**Typical Radar Frequencies, Applications, and Wavelengths**

| Frequency | Application | Wavelength |
|---|---|---|
| 150 MHz | Long-range Surveillance | 2 m (6.5 ft.) |
| 2 GHz | Surveillance | 15 cm (6 in.) |
| 10 GHz | Tracking | 3 cm (1.2 in.) |

preciably affect the aircraft's RCS because the entire aircraft body or individual wavelength-sized aircraft sections will act as a reradiating antenna of the incident-radar wave. The geometry of the viewing aspect of the illumination radar is important because the reflected wave's mutual-phase interference will cause an RCS in this frequency region to fluctuate greatly.

In this high-frequency region, where the radar wavelength is much shorter than the aircraft's physical dimensions, distinct scattering centers, such as engine intakes and corner reflections from the wing and fuselage joint and gaps in skin panels and access doors, add significantly to the RCS. The mutual-phase interference is not as significant as these wavelengths. High-frequency scattering comprises the most significant component of RCS and has specific characteristics that must be understood to design and operate an LO aircraft. This scattering consists of specular reflection, edge and corner reflection, aircraft skin seam and gap reflection, surface-traveling wave reflection, shadow-boundary reflection from creeping waves, and reflection from ducts, intakes, cavities, and corners.[3]

Specular reflection occurs when radar waves strike a smooth, flat surface or boundary, and a large part of the radar wave is reflected at an angle that is equal to its incoming angle. This specular reflection is similar to reflection from a mirror (see fig. 7). Specular reflection from a curved edge tends to radiate in all directions (i.e., isotropically). Specular reflection generally comprises the larger part of an aircraft's RCS, giving rise to efforts to reduce an aircraft's RCS focus on this area during the designing of LO aircraft. Reducing the RCS is a matter of using certain aircraft shapes to redirect the reflected waves away from the transmitting radar. The direction of the reflection can be predicted using computer modeling determined on RCS ranges. A simple diagram, using basic optical-ray physics, demonstrates the reflection principle (fig. 11). The part of the radar wave that is not reflected will be absorbed by the surface or will move along the surface, assuming a continuous electrical conductivity.

Scattering by diffraction is the tendency for incident radar waves to bend around or scatter from the edge of an obstacle

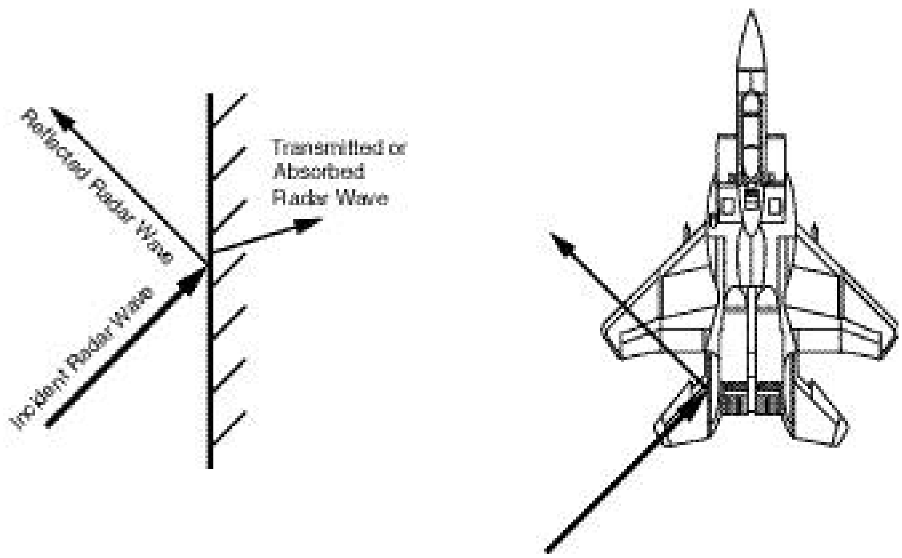
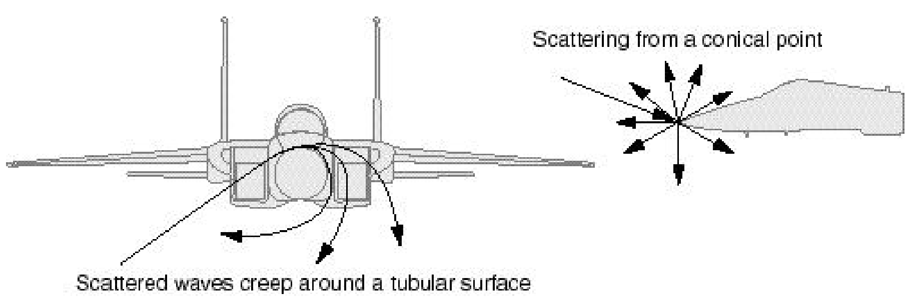



**Figure 11. Specular Radar Scattering**

or boundary that they strike. The surface features that easily diffract radar are edges, corners, and tips (fig. 12).

Surface traveling waves (STW), part of the high-frequency region, also contribute to the RCS of aircraft. STW result when

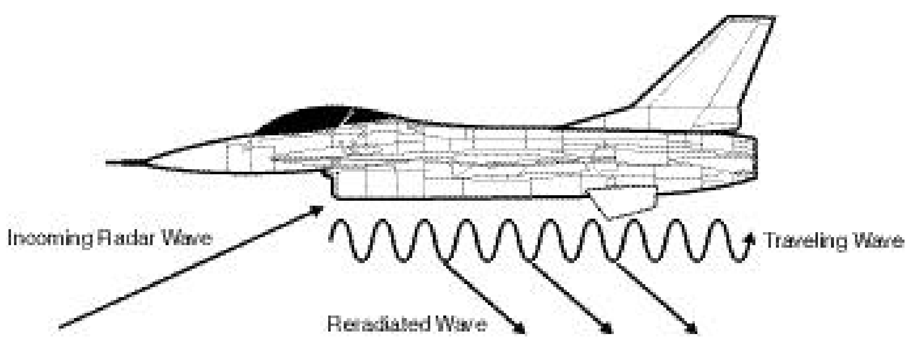



**Source:** Doug Richardson, *Stealth: Deception, Evasion, and Concealment in the Air* (New York: Orion Books, 1989), 29.

**Figure 12. Radar Wave Diffraction**

a portion of the incoming radar wave strikes the aircraft skin at a near-grazing angle and travels along the surface of the aircraft until it reaches the far end of the aircraft structure or encounters a surface or electrical discontinuity such as a seam or gap in the skin of the aircraft. The STW will then split into two waves of approximately equal magnitude but opposite direction. These seemingly small surface discontinuities are large in comparison to the wavelength of the radar frequency and make good radar reflectors. This first part of the STW is called the forward traveling wave. When the far end of the aircraft structure is reached or a surface or electrical discontinuity is struck, part of the forward traveling wave reflects, reverses direction, and becomes a backward traveling wave. This backward traveling wave will then move back along the surface of the aircraft toward the transmitting radar source. When it reaches the edge of the aircraft surface, this backward traveling wave will radiate in an "end-fire" fashion toward the transmitting radar (fig. 13). Hence the backward component of the STW can contribute greatly to the RCS of an aircraft. A properly polarized STW contributes strongly to an RCS in cases where an aircraft has long smooth structures, where the incident radar waves are of a high frequency and when the radar strikes the surface at low angles.

Creeping waves may also contribute significantly to an aircraft's RCS. Creeping waves occur when the incident radar




**Source:** Doug Richardson, *Stealth: Deception, Evasion, and Concealment in the Air* (New York: Orion Books, 1989), 31.

**Figure 13. Surface Traveling Waves**

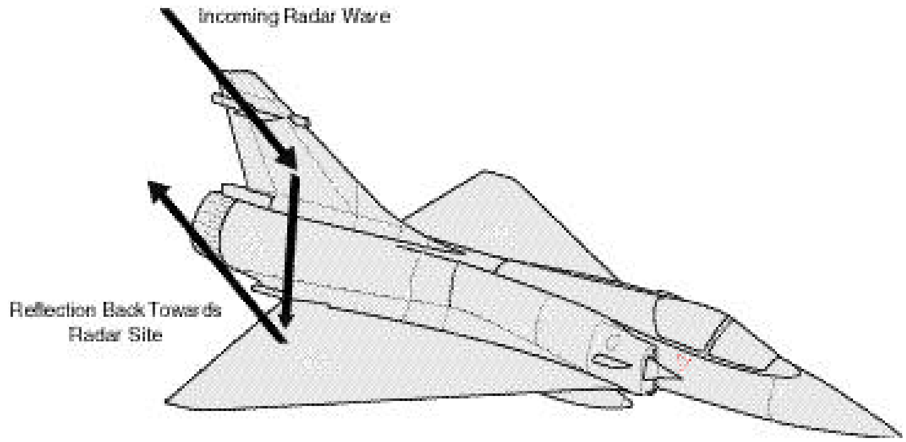
energy strikes the “shadow boundary” or edge of the illuminated object. The creeping wave will travel around the back or hidden part of the aircraft surface, then return towards the transmitting radar (see fig. 13). For conventionally designed aircraft, the creeping wave’s RCS contribution is not significant relative to other stronger contribution components of the RCS. For an LO aircraft, however, the contribution to the RCS from creeping wave reflection may be significant since the other contributing RCS components have been reduced. This is true, though, only if the ratio between the size of the specific part of the aircraft structure considered a creeping wave-reflection producer and the incident radar’s wavelength is less than 15 to 1.[4]

Comprehending aircraft design RCS requires understanding the radar scattering of basic shapes such as a three-sided corner reflector, a two-sided corner reflector, a flat plate, a cylinder, and a sphere. These shapes are arranged in descending order of the degree to which they reflect radar energy. This order assumes that these shapes are arranged with respect to the illuminating radar so as to produce the strongest specular return when the flat side plate face is perpendicular to the direction of the incoming radar energy.

Corner reflectors produce large radar returns. In much the same way that a billiard ball will bank off the adjacent rails and return to the player, any radar wave entering the corner reflector will come out and cover a broad scattering angle, thus increasing the possibility of detection by a searching radar (fig. 14). Thus, corner reflectors can make small vehicles appear very large to a radar. Anytime two or three sides of an object are joined together at right angles, they will produce a strong reflector. One of the main concerns in designing LO aircraft is elimination of corner reflectors to reduce the RCS.

Given the pattern of radar scattering by simple shapes, an LO aircraft design should not have any flat surfaces that could be perpendicular to a searching radar. In practical terms, this goal is not possible since useful aircraft design requires flat surfaces. In addition, the orientation of the aircraft to the threat radars cannot always be optimized to decrease an RCS.

In the nose-on viewing angle, RCS is predominantly from the engine intakes, since they act as corner reflectors. Radar




**Source:** Doug Richardson, *Stealth: Deception, Evasion, and Concealment in the Air* (New York: Orion Books, 1989), 31.

**Figure 14. Two-sided Corner Reflector on an Aircraft**

antenna in the nose of the aircraft and the cockpit also make a large RCS contribution. Leading edges of the wings are major RCS contributors and reflect radar much as a cylinder does when viewed on its longitudinal axis. In the broadside view, the fuselage, tail, and engines act as major scattering centers. The corners formed by the wing-fuselage joint and the tail assembly also act as strong radar reflectors. The trailing edges of the wings reflect radar, and in the tail-on aspect, the contributions of the engine exhaust to the RCS are significant. It is important to note not only what the sources of strong RCS contributions are but also that these contributions vary greatly with the viewing aspect azimuth and elevation.

The major and minor scattering centers of an aircraft teamed with the mutual interference of adjacent radar reflection result in RCS measurements that vary markedly over small changes in viewing angle. The glint and scintillation of conventionally designed aircraft can vary as much as 80 decibels, which is like saying that the target radar return can be 100 million times larger than the smallest return.

## Radar Cross Section Reduction Techniques

Since radar is the primary method an air defense system uses to detect and direct interception of penetrating aircraft, designers of combat aircraft have a vested interest in reducing the RCS of aircraft. Some of the specific benefits of radar cross section reduction (RCSR) are listed.

1. Prevent, delay, or degrade the enemy's radar-detection ability.
2. Force the enemy radar to increase its own transmitting power and, in doing so, making it easier for the penetration aircrew to detect the enemy's presence via their onboard electronic support measures.
3. Prevent easy target classification of the penetrating aircraft through characteristic radar "hot spots."
4. Reduce the electronic countermeasures (ECM) power required to defend the penetrating aircraft.
5. Increase the effectiveness of onboard jamming systems.
6. Reduce the amount of chaff expended to hide the aircraft.
7. Increase the deception opportunities by intentionally unmasking the low RCS with off-and-on-again radar returns that can confuse and disrupt an air defense system.
8. Increase the vulnerabilities of the searching radars to background and false radar returns, both of which will degrade their tracking loops.

RCSR can be achieved by managing the scattering centers on the aircraft. There are four methods to manage those centers. The methods in decreasing order of effectiveness are shaping, using radar-absorbing materials, employing passive cancellation, and transmitting matching radar waves to effect active cancellation.[5]

### Shaping

Shaping is the most effective means of reducing RCS and generally works by redirecting the incident radar energy away from a threat radar. The reflecting surfaces (e.g., edges, engines, flat surfaces, intakes, and other reflectors) are made so that as the aircraft performs its planned mission, they reflect the incident radar energy in other directions rather than creating a strong scattering lobe back toward the threat radar.

The RCS of an aircraft is made up of many individual scattering centers. The greatest success in RCSR has been made by identifying those strongest radar reflectors and using shaping techniques to reduce their RCS contribution. After an LO shape is designed, additional RCSR steps can be taken with radar absorbent material (RAM) and radar cancellation techniques.

The first step in shaping is to undertake a mission analysis to determine the offensive mission requirements (e.g., payload, range, and so on) and the enemy threat system's order of battle. The threat analysis will determine the most likely and most threatening engagement sectors or specific fields of view. Aircraft shaping must provide for cargo and/or weapons carriage, fuel capacity, and effective sensor employment while seeking to move the radar reflections and returns out of these engagement sectors and fields of view and into another sector that is not so easily detected or threatening if the reflected radar is observed. This shaping strategy has its challenges.

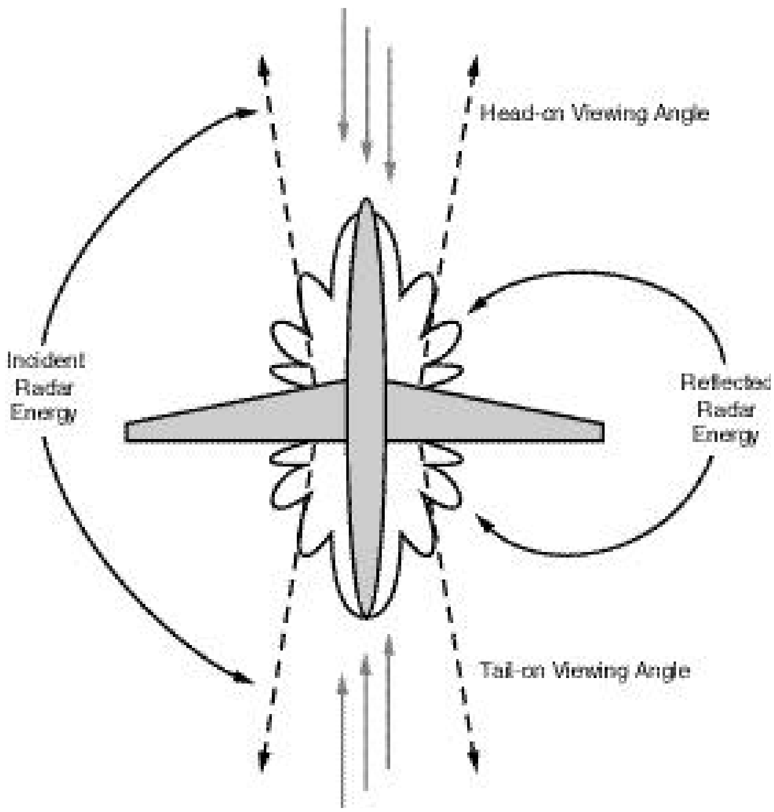
While the most dangerous frontal sector's radar returns have been minimized, the less threatening beam and tail aspect detection sectors must also be reduced to achieve an aspect or viewing-angle-balanced RCS. Assuming that the greatest threat to detection and interception will come from the frontal aspect, the incident radar energy that is reflected will be redirected, due to shaping, away from the radar receiver location and into a different set of viewing angles not covered by radar detection sites. This redirection will work if the threat analysis is correct, a thorough strike route has been planned, and flexible tactics are employed.

There are several shaping methods for this radar energy reflection redirection. The first method of reducing RCS is to sweep the wings back at a very large angle and avoid long constant curves that will reflect radar into many viewing angles. The specular reflections from the leading edge will be to the side of the aircraft's flight path into tight viewing angles. Minimizing the effects of the engine intakes is another method of reducing RCS. The mission profile of the aircraft may make observation of its intakes highly unlikely if it operates at high altitude. In this case, the intakes could be placed on the upper surfaces of the aircraft and hidden from the enemy's ground radars. Next, wing and fuselage joints can be smoothed to reduce corner reflections. The emphasizing of these lower-threat engagement sectors by redirection of additional radar reflections or "spikes" can be acceptable if our mission profile and threat analysis are correct.[6] It is to the benefit of the LO aircraft if these spikes can be narrow so as to provide the redirection of the reflected radar energy into a viewing angle that has a lower threat potential for detection and engagement. The LO penetration potential can be further enhanced through smart flight planning and mission employment tactics that will also control the detection opportunities of other sensors in an enemy integrated air defense system (IADS).

A discussion of the shaping design progression will be useful to understand how controlled reflection of incident radar energy is a major contributor to the LO qualities of an aircraft. In a conventional planform (fig. 15) where the leading edges of the wings have a small taper or sweep and the trailing edges are perpendicular to the aircraft's longitudinal axis, the major RCS contributor in the forward aspect will be the leading edges of the wing, especially where the radar's line of sight strikes the leading edge in a 90° angle. When looking at this aircraft design from the rear and at small angles above or below, the major RCS contributor will be the trailing edges.

The first attempts at RCSR for this aircraft design would be to sweep the wings further back (fig. 16). The RCS reflection from both the leading and trailing edges would shift away from a direct frontal or rearward reflection viewing angle.

In the next design step, the major RCS contribution from the wing's leading edges could be further lessened by sweeping with wings even more aft. The length of the wings increases as their sweep increases, and the new length also increases the strength of a threat radar return. One way of spreading that strengthened RCS return over a greater viewing angle would be to shape the wing's leading edge with a curve (fig. 17). This curve would not decrease the strength of the



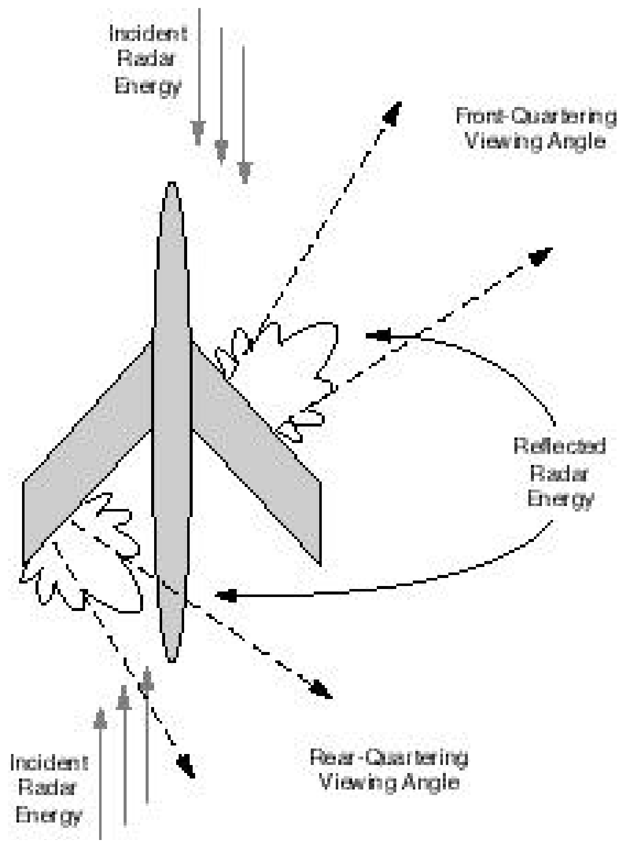

**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 213.

**Figure 15. Radar Reflection of a Conventional Aircraft Planform**

RCS return lobe, but would spread the energy out over a larger viewing angle.

It is considered more advantageous to maintain an LO signature if shaping moves the radar returns into specific, less threatening and detectable viewing angles. The curved leading edge defeats this goal by increasing the radar return's viewing angles while only slightly decreasing the strength of the return.

As the LO design development continues, a highly swept, straight leading edge is chosen (fig. 18). It has a strong radar return that is tightly restricted to a narrow set of viewing angles. These radar return spikes are well away from the

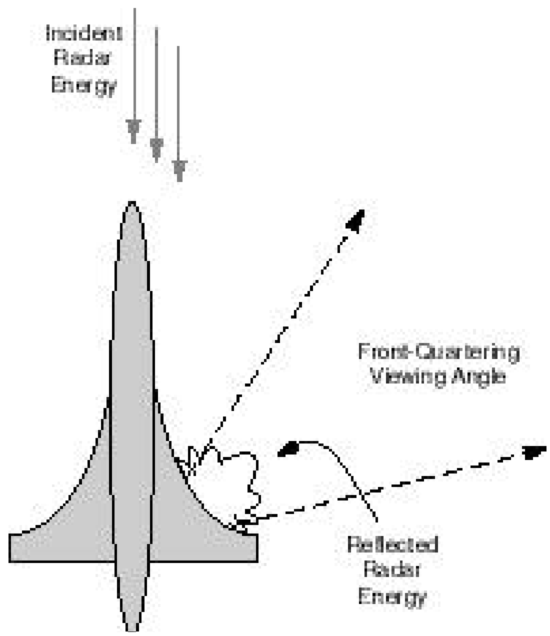



**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 213.

**Figure 16. Radar Reflections from Aircraft Planform with Increased Wing Sweep**

nose-on high-threat viewing angle, and their exposure to other threats during a mission can be controlled with smart route planning and tactical maneuver.

To design an effective LO aircraft, the remaining nonspecular RCS contributors must also be considered and reduced. These nonspecular RCS reflection, "fuzzballs," radiate and reflect in many viewing angles.[7] On a conventional design, these fuzzball contributors—aircraft skin and electrical conductivity discontinuities such as seams, gaps, and changes in the material's electrical properties—produce a very detectable surface traveling-wave-radar return. The STW moves from the wing

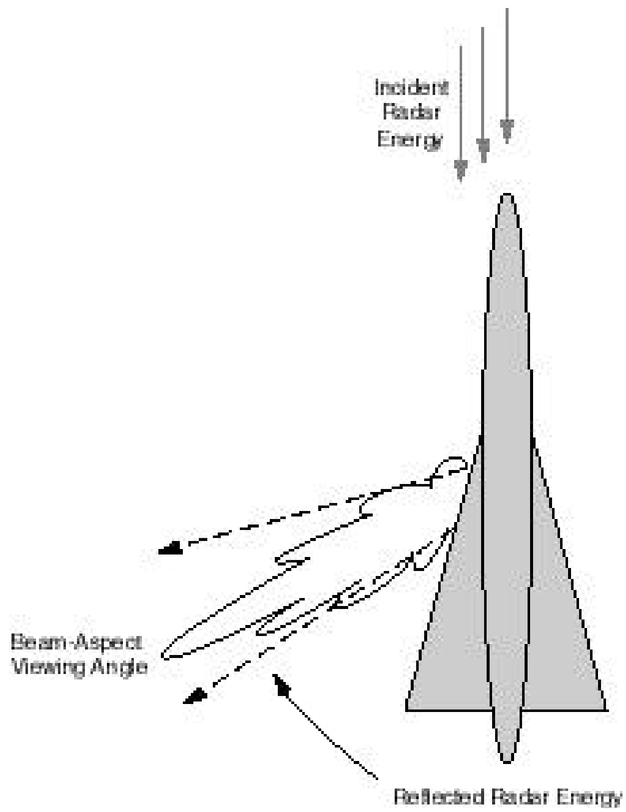



**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc. 1985), 214.

**Figure 17. Radar Reflection from an Aircraft Planform with a Curved and Swept Leading Edge**

leading edge to the sharp discontinuity at the trailing edge and the wing tips. The STW reflection off the straight trailing edge returns back toward the nose-on, high-threat forward-aspect viewing angle. To decrease this STW contribution, we can reduce the strength of the reflection into the high-threat nose-on forward aspect by curving the trailing edge and rounding the sharp wing tips to shift their return into viewing angles other than the nose-on, high-threat sector (fig. 19). Using RAM in the ends of the aircraft structure will also reduce the STW intensity.

Surface and electrical discontinuities such as skin seams and joint gaps serve as great reflectors of the STW. Improved design, construction, and maintenance practices can eliminate these skin reflections, present a long, smooth, and electrically consistent surface to the STW, and allow the RAM at the ends of the fuselage to attenuate and diminish the traveling wave's intensity, resulting in a very low radar reflection.[8]




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 214.

**Figure 18. Radar Reflection from an Aircraft Planform with a Highly Swept Straight Leading Edge**

The shaping design efforts described here have centered on decreasing the aircraft's total radar signature by redirecting the existing radar returns into other areas that are not as easily detected by the highest threat systems the aircraft may most likely encounter. The most dangerous radar returns have now been redirected into front quartering and beam aspects. Detection of these returns, while not as threatening, is still a concern and a goal for the design engineer to decrease and for the mission planner and aircrew to handle with smart planning and in-flight tactical execution.

These redirected radar reflections combine with the returns from such scattering centers as the engine pods, wing pylons,

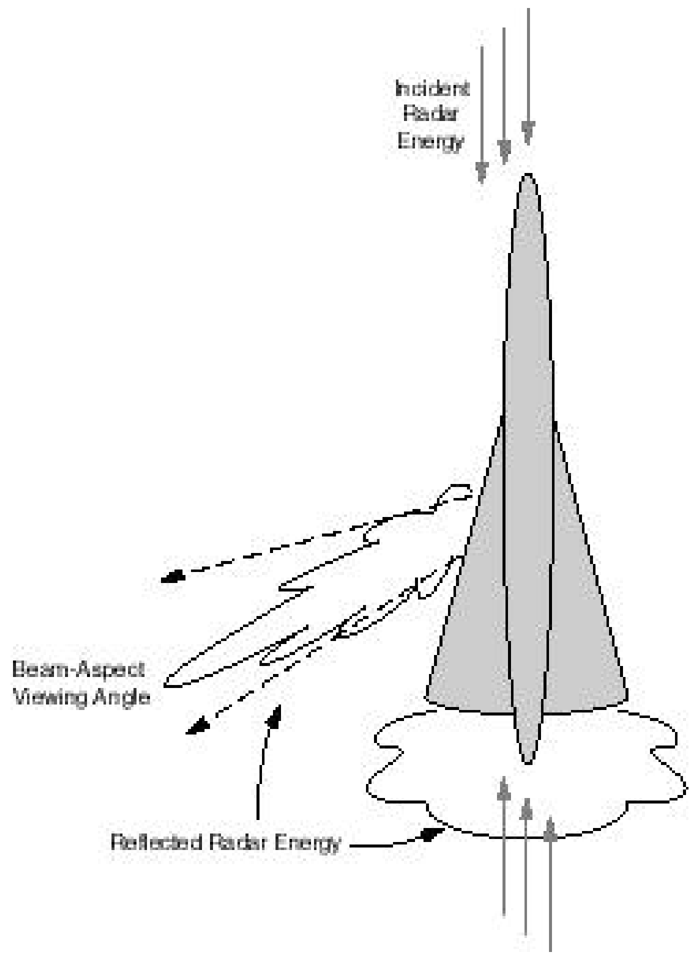
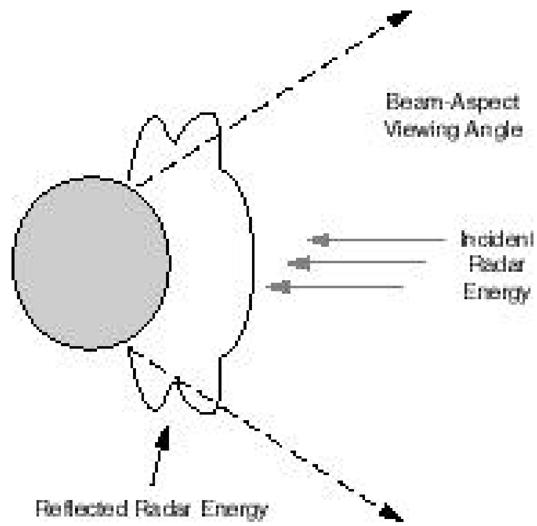



**Figure 19. Radar Reflection from an Aircraft Planform with a Highly Swept Leading Edge and a Curved Trailing Edge**

and wing/fuselage joint to produce large radar reflections. Shaping also allows us to decrease the fuselage RCS contribution. A standard fuselage design produces strong radar returns in the beam aspect and also into a broad number of viewing angles (fig. 20).

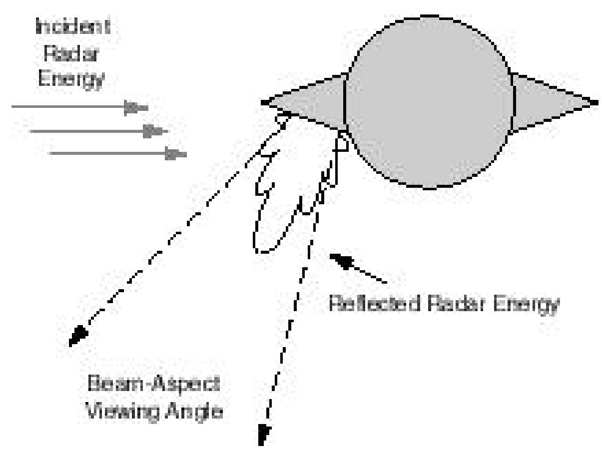
The addition of a chine that blends the wing into the fuselage and can flatten the beam aspect of the fuselage greatly diminishes the radar returns in the beam aspect (fig. 21).




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 215.

**Figure 20. Basic Aircraft Fuselage Section**

The design can be taken further by blending the chine into a wing that is flat along the lower surface (fig. 22). The result would be an LO aircraft optimized for stealth operations at high altitudes. The flat wing blended into the fuselage chine



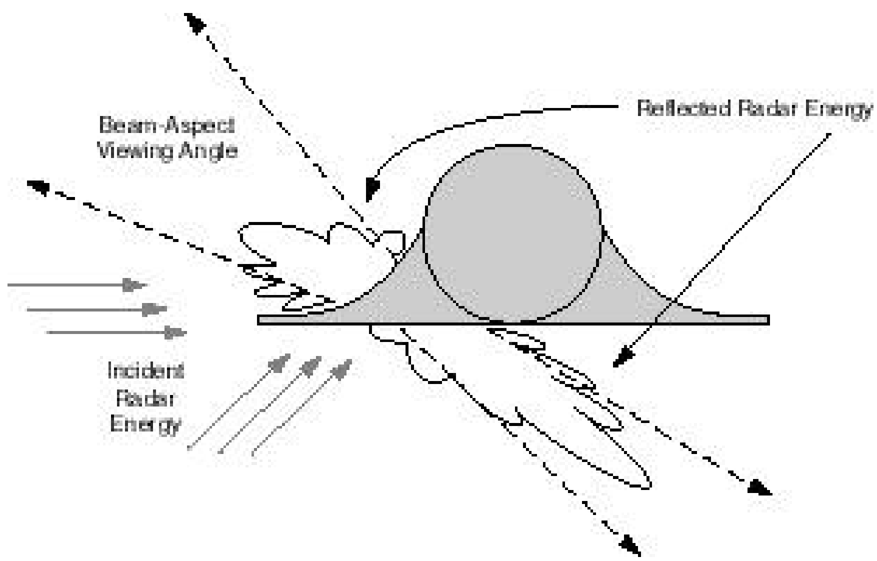

**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 215.

**Figure 21. Aircraft Fuselage with Symmetrical Chine**

RCSR would shield and redirect spike reflection away from searching ground or airborne radars.

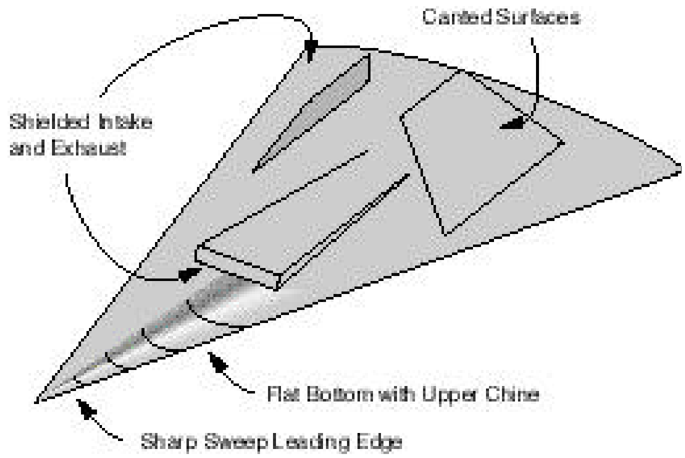
The logical extension of these wing and fuselage shaping designs from the forward- and beam-aspect viewing angles can be combined into a single integrated design (fig. 23). Here, the wings are highly swept with straight edges. The wing tips and trailing edges are rounded and curved. The wing is flat on the bottom, low mounted, and blended into the fuselage with a chine above. The vertical fins are canted inward to redirect beam-aspect radar illumination into another elevation viewing angle, and, in this instance, the engine intake is mounted on top of the aircraft to reduce its exposure to radar energy from ground threats during high-altitude penetration.

The design of cavities such as engine intakes and exhausts is very important to RCSR. These cavities can function as three- or two-sided corner reflectors, and the face of the engine fan, compressor, or turbine is a perfect radar reflector and an identification target for advanced radars. Some solutions to the intake question are placement and masking. If an LOP operates mainly at high or low altitudes, then placing the




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 215.

**Figure 22. Aircraft with Chine and Fuselage Blended**




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 216.

**Figure 23. LO Aircraft Design with Fuselage and Wing Shaping Applied**

engine intake and exhaust above or below the wing will shield those cavities and engine compressor or turbine blades from radar illumination/reflection. The engine intakes can also be masked by serpentine air passages that will allow the radar waves to enter but not reflect nor exit. This trapping is done using an S-curved intake path and positioning baffles so the incident radar cannot directly strike the intake walls or engine fan nor exit. Once trapped, the radar energy can be absorbed by RAM coating and materials in the intake structure.

Aircraft cockpits can also produce tremendous radar reflection. Since windscreens are invisible to radar energy, the many angles and flat radar-reflecting surfaces inside the cockpit make it a significant RCS hotspot. When the canopy is coated with transparent but electrically conductive substances such as a thin layer of metal, the radar waves will not penetrate the canopy surface. The radar waves will follow the windscreen surface or reflect with a lower average intensity into wide viewing angles from this curved surface. Visible light can enter and leave easily, permitting unaffected flight operations; but radar will not pass through and reflect off the many flat surfaces and corner reflectors within the cockpit.

On-board aircraft ground mapping or intercept radar is another challenge for the LO aircraft designer. Besides producing the high radar reflections typical of a cavity, the radar antenna itself also adds greatly to the RCS. However, new radar antenna designs such as a flat plate or planar arrays can be tilted to reflect and redirect incident radar energy. The antennas can still function effectively by electronically steering their beams. Another RCSR technique is to build a radome that is made of material that allows specific frequency bands to pass through it. This concept will be discussed in more detail in the section on passive cancellation.

Proper shaping to achieve an LO RCS also depends on making small surface details such as the skin seams, gaps, and rivet heads less visible. This RCSR major effect is on reducing back-scattered STW. If RCSR, by large-scale shaping, is successful at redirecting specular or spike reflections from flat surfaces and external features of the aircraft, then the RCS contributions from STW may not be a significant RCS concern. The assembly tolerances and maintenance practices will have to be improved by several orders of magnitude above today's conventional aircraft standards to meet and maintain an LOP's radar-performance specifications.

## Radar-Absorbing Materials

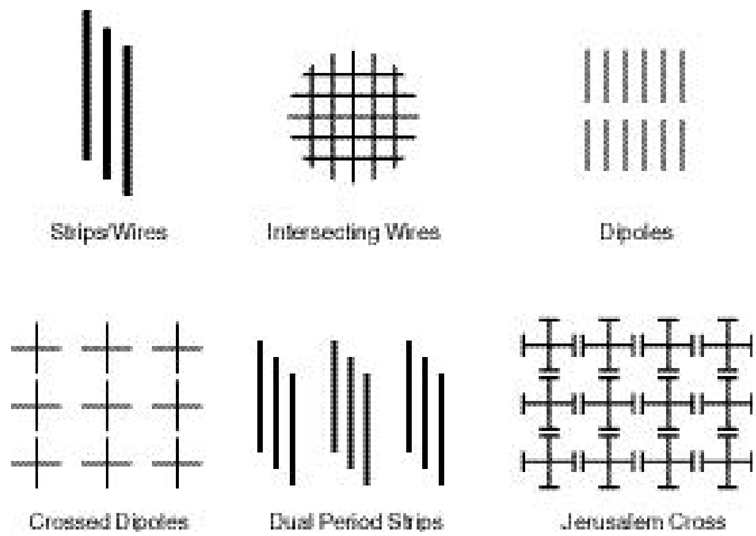
While shaping achieves the highest reduction in aspect-dependent RCS, RAM can further reduce the amount of incident radar energy that an aircraft will reflect. These materials do just as their name implies: they reduce reflected radar energy by absorbing the incident radar energy. Basically, these materials dissipate electromagnetic radar energy much as an electric circuit resistor transforms the electricity passing through it into heat, but what little heat is created will not be enough to be detected with infrared sensors. The heat produced from energy absorption in RAM is insignificant and undetectable when compared to that from engine exhausts, intake, jet plume, or even aerodynamic heating of the aircraft skin.

Some materials absorb the electrical component; others, the magnetic-wave component. For example, carbon is a dielectric or a poor conductor of electricity and thus will absorb the electrical component of the radar wave. However, materials that primarily absorb the electrical wave must usually be several inches thick to work against the complete radar frequency band, especially at the low frequencies. The bulk of materials needed for effective absorption would add too much weight to the aircraft.[9]

The molecular structure of compounds that contain oxides of iron (ferrite) make excellent material for absorbing the magnetic component of the radar wave. It can be made thin enough to be effective and therefore will not add restrictive weight to the aircraft. Metals that absorb the magnetic component of radar waves need only be one-tenth as thick as dielectric RAM to provide the necessary frequency-band coverage. Magnetic RAM can also reduce the intensity of STW. By using graduated thicknesses of magnetic RAM on the nose and on the leading and trailing edges of the wing and tail section, the STW strength will be diminished and absorbed. Any backward STW that remains will be of relatively too low intensity for easy detection.

Iron-based RAM can be applied to the aircraft in several ways. The RAM can be made into small tiles and bonded to the aircraft's structure or skin. The RAM can also be applied in support material such as rubber matrix sheets and molded or glued to the aircraft. Another technique for applying RAM includes spray painting with an iron-based paint. This technique requires special equipment, and several layers must be applied to achieve the desired radar absorption. This "iron paint" has advantages over tiles or matrix RAM sheets, because it can more easily cover irregular or double-curved surfaces.

Protecting the aircraft cockpit from radar is an important task. An aircraft cockpit contains many two- and three-sided corner reflectors and is a strong contributor to the RCS of an aircraft. The coating used on the cockpit transparencies, while preventing the radar transmission from entering into and reflecting out of the cockpit, reflects too much radar energy itself into broad viewing angles. A RAM technique to solve this problem is embedding a circuit-analog absorber grid in the canopy windscreen material. By embedding a network or grid of thin wires of certain design and dimensions (based on radar wavelengths to be absorbed) in the windscreen or canopy material, the grid can effectively absorb incoming radar energy and prevent its entering or exiting the aircraft cockpit. The advantage of using this technique is that the grid is light and has marginal volume. The difficulty is that a special pattern is required for each band of frequency to be absorbed.




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 259.

**Figure 24. Circuit-Analog Absorber Patterns**

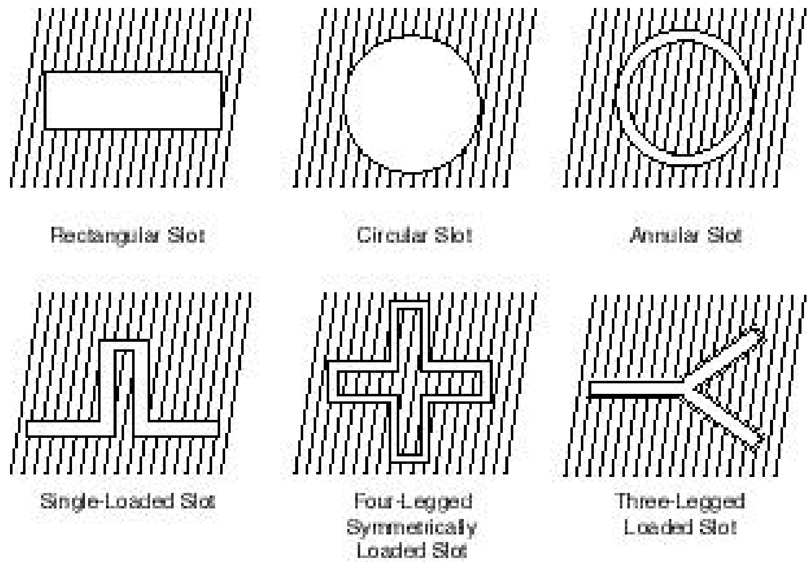
Hybrid RAM can be made from layers of magnetic and dielectric absorbers. Magnetic RAM functions best at low-radar frequencies, and materials are most effective when they absorb across a desired band of frequencies. These types of RAM are called broadband RAM. Materials that also absorb a small band of frequencies are called resonant RAM. RAM is usually applied by using layers of varying thickness and different absorbing characteristics separated by free spaces. The material compounds and degree of thickness used vary for the particular position on the aircraft where the RAM is to be mounted.

Reinforced carbon-carbon can be used as economically as RAM. These compounds are good radar absorbers and have high-heat resistance. These qualities make it very useful for shielding high-temperature areas such as engine exhaust cavities.[10] Recent advances permit the use of polyanaline plastics and Schiff-based salts as radar-absorbing materials. The polyanaline plastics can be manufactured into different shapes, and their electrical conductivity can be varied with the application of low-voltage electricity. This property allows these plastics to either transmit or stop particular radar energy bands. Compounds made of Schiff-based salts absorb radio and radar waves well and weigh much less than traditional dielectric or magnetic radar-absorbing materials. These salts can be embedded and applied in a supporting matrix.

**Passive Cancellation**

Passive cancellation of incident radar energy is a technique of employing specifically constructed aircraft body cavities to reflect radar waves in such a way that they will mutually interfere with and continually cancel out incoming radar, thus reducing an aircraft's RCS. In reality, this RCSR technique is not particularly effective. The large spectrum of radar frequencies used by threat radars and the precise body cavities required on aircraft—design features intended to cancel out radar returns—may instead reinforce the radar signal.

One offshoot of passive cancellation that has useful application is the frequency selective surface (FSS). The surface masks a cavity such as an internally mounted sensor and the highly radar-reflective material within from scattering incident radar energy. The FSS is made up of certain geometric patterns that can be tuned to allow only a very precise frequency that matches the aircraft's radar to be transmitted or received through the surface (fig. 25). Any other out-of-band incident radar energy will not penetrate the FSS and scatter off the many radar reflective surfaces inside the radome.[11]




**Source:** Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 259.

**Figure 25. Frequency Selective Surface Geometries**

### Active Cancellation

The physics of electromagnetic radiation and also of radar waves permits the cancellation of a reflected radar wave by actively transmitting a radar wave that matches the frequency and amplitude and is exactly 180° out of phase with the reflected wave. This technique, while simple in concept, is a technical challenge. Extremely high-speed electronics are required to detect, analyze, and transmit the cancellation signal. The cancellation radar wave must also be transmitted in the proper azimuth and time frame. The trade-off between LO benefits versus the cost and quantity of available aircraft equipment storage space for the required electronics makes active cancellation an RCSR technique whose time has not yet come.

## Merging RCSR Techniques with Aircraft Design

Reducing the RCSR of an existing aircraft or one under design is a process of compromise. The main factor is balancing cost with higher levels of RCSR, flight qualities, weight, mission performance, and increased LO maintenance processes. This new area of aircraft engineering will break ground not only in the design of LOPs but also in the production and operation of such vehicles. Some sacrifice in flight performance may be necessary. The possible design impacts of RCSR are reduced aerodynamic performance, added weight, reduced payload, reduced range, and increased maintenance to preserve the LO qualities of the aircraft skin and structure. Addition of RAM will increase the aircraft's LO properties but will not improve fuel capacity, payload, or range.

Besides making compromises on cost and performance, we must adopt design production techniques to build these new types of aircraft. Traditional aircraft have not been developed and manufactured to achieve LO quality. New levels of skin-seam and gap tolerances are required to reduce the reflection contributions of STW. Improved flight-line maintenance practices are required to sustain the LO qualities during normal and combat operations. For example, aircraft skin panels are routinely opened and closed for system checks and repairs. For that reason, the seams and fasteners must be designed not only to provide a very tight fit and smooth finish, but they must also be able to stand a high-use rate without losing their LO qualities. The smoothness of the skin, the radar-absorbing qualities of the RAM, and the special paints applied may require protecting the aircraft from the environment as much as possible. Operators should provide suitable basing facilities and potential restrictive operational training guidelines to maintain an LO aircraft's low-radar signature.

## Infrared Detection

As the ability to detect an LO aircraft by radar is reduced by the previously discussed RCSR techniques, other portions of an aircraft's signature must be reduced to maintain the balance throughout the detection spectrum. Another significant area to detect aircraft is by its infrared (IR) emissions. The sources of IR radiation are the hot metal parts of the engine(s) (e.g., fan, compressor, turbine blades, and exhaust nozzle), the hot jet exhaust plume, reflected solar radiation, and the aerodynamic heating of the aircraft's leading edges. These IR sources must also be considered against the ambient heat of the environmental background. Engineers who design LO aircraft must analyze and reduce or mask these IR energy sources.

The IR sensors or detectors used by an IADS are of a passive type. That is, the sensors receive only the emitted IR radiation from the target. One of the challenges to defeat these IR sensors is knowing when they are active and when detection has occurred or is about to occur. The general solution is to greatly reduce the IR signature of an LO aircraft at all times since knowing when the sensors are active is difficult.

The primary source of infrared radiation on an aircraft is the hot engine parts. It is possible to reduce the observed heat by using a lower-thrust power setting or by limiting use of the afterburner. An aircraft can be initially designed with or modified to use a high-thrust turbofan, nonafterburning engine; the use of such a turbofan will produce a cooler overall engine installation and exhaust stream due to the bypass air's shielding the hot engine and exhaust plume.

Hot engine parts can be shielded from the most likely viewing angles by enclosing the exhaust nozzles in the aircraft's fuselage or in the wing and tail surfaces. The engine exhaust nozzles also can be designed with louvers that will limit the viewing sectors to a small set of viewing angles directly behind and above or below the aircraft, depending on the most likely mission profile. RAM air can also be channeled through the engine bay to prevent hot spots from developing on the aircraft skin and structure. The mixing of engine bypass or RAM cooling air with the hot exhaust stream can reduce the intensity of the exhaust plume as a source of IR emissions. The turbofan engine is effective at this task. The greater the bypass ratio—the total amount of air pumped through the fan and the turbine versus the amount of air that passes only through the turbine (hot section)—the greater the cooling benefits. The use of elliptical or rectangular exhaust nozzles will also spread the hot gases over a greater area, thus increasing the cooling of the exhaust and reducing the IR detectability of the aircraft at longer ranges.

Reflected solar radiation as an IR source can be decreased by using special paints that do not readily reflect heat. The aerodynamic heat produced by high-speed flight could be diminished by using the fuel stored in the fuselage and wings as a leading-edge heat sink or by operating the aircraft at subsonic speeds when the mission profile would be susceptible to IR detection. Another option may be to use heat sinks and IR absorbers to reradiate heat from aerodynamic friction and to operate the aircraft's avionics and environmental control systems in IR frequencies that the atmosphere's water vapor will readily absorb and mask. Heat from these sources will then not contribute to the detection of the aircraft by IR sensors.

## Visual Detection

Several characteristics of an aircraft contribute to its visual detection. These features include size, shape, point color(s), contrast, movement and maneuver, contrails, canopy, body glint and glare, exhaust smoke, and ground shadows.[12]

### Size

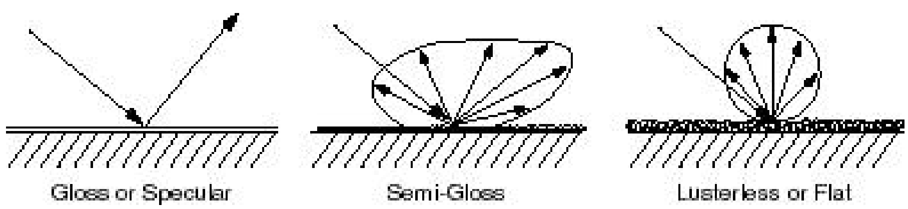
The size of an aircraft is one of the greatest factors in determining the range at which an observer can first see the aircraft. The aircraft's size is generally determined by the required aircraft performance and mission requirements such as range, payload, and flight characteristics at high and low speeds. Operational consideration should be given to flying the LO aircraft in a manner that presents the smallest dimension or planform view to the most likely IADS observer or sensor.

### Shape

The shape of an aircraft contributes markedly to its visibility and is determined mainly by design requirements. As LO becomes more of an operational need and a design requirement, then aircraft shapes will change to favor a balanced LO signature. Long, thin, smooth shapes with a low-profile cockpit, integrated fuselage and engine intakes, and exhaust have a smaller probability of visual detection than do squat, thick aircraft that use many sharp angles, have large surface discontinuities such as engine pods, and are configured with external stores. Gently curved designs have a smaller visual signature than boxy aircraft. An angular aircraft shape produces many shadows and, consequently, many areas of dark to light contrast that may attract an observer's attention.[13]

## Paint Color

Blending patterns of various shades of paint in a camouflage scheme is an accepted method of reducing visibility of military aircraft. Since an LO aircraft's high priority is to avoid detection, camouflage paint selection and scheme design should emphasize blending with the background. Air Force labs have determined that the "brightness" or reflectance of aircraft paint, not necessarily the color or the pattern, is the major factor in reducing the range at which the human eye first acquires, then focuses, on an airborne object. The laboratories recommend using a specific reflectance paint that matches the most likely characteristics of the ground and sky backgrounds against which aircraft will fly in order to make an attacking aircraft less detectable (table 5) (fig. 26).




**Source:** *The Camouflage Handbook,* AAFWAL-TR-86-1028 (Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories, 1986), chap. 1, 4–8.

**Figure 26. Paint Reflectance Concept Examples**

A secondary decision in camouflaging aircraft usually is to match the predominant background color. The color of paint selected can differ, based on the observer's position. Therefore, we often choose one color paint for the top and a different one for the bottom or side of the penetrating aircraft.[14] The final determining factor on which color, reflectance, or design scheme is chosen should be based on whether visual detection

**Table 5**

**Luminous Reflectance of Typical Terrain/Background Materials**

| Background Feature | Approximate Reflectance (Percentage) |
|---|---|
| Water | |
| Bay | 3–4 |
| Bay and River | 6–10 |
| Inland Waters | 5–10 |
| Ocean | 3–7 |
| Deep Ocean | 3–5 |
| | |
| Vegetation | |
| Jungle | 3–6 |
| Forest | 4–10 |
| Plowed Fields | 20–25 |
| Green Fields | 3–6 |
| Wheat Fields | 7–10 |
| | |
| Soil/Snow | |
| Bare Ground | 10–20 |
| Very White Ground | 11–15 |
| Some Trees | 7–10 |
| Dry Sand | 24–31 |
| Rock | 12–30 |
| Snow | 70–86 |
| | |
| Man-made | |
| Concrete | 15–35 |
| Blacktop | 8–9 |
| | |
| Clouds | |
| Dense and Opaque | 55–78 |
| Thin | 36–40 |

**Source:** *The Camouflage Handbook,* AAFWAL-TR-86-1028 (Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories, 1986), chap. 1, 3–14.

is probable and on scenarios where the benefits of a camouflage paint scheme are the greatest.

### Movement and Maneuver

LO penetrating aircraft can greatly increase their visual detectability if they perform significant maneuvers. The maneuvers most likely to attract visual attention are steep climbs or dives and large turns where a wing flashes or the planform of the aircraft is exposed to a head/tail-on, quartering, or beam observer. Also a maneuvering aircraft may appear larger and therefore increase its visual detectability. A balanced signature can be maintained by limiting maneuver during LO operations.

### Contrails

The elongated, tubular-shaped cloud of ice crystals or water vapor made by the rapid cooling of an aircraft engine exhaust that forms a few hundred feet behind the aircraft can easily reveal the aircraft's presence during day or night operations. US air combat experience shows that when contrails were visible, losses greatly increased. Generally, a ground observer can see an aircraft "conning" more than 30 miles away. The same aircraft, when not leaving a contrail, would be visible only up to six miles. An observer in a threat aircraft can normally see another aircraft at seven miles without contrails. If the same aircraft is producing contrails, the aerial observer may see the aircraft up to 60 miles away (fig. 27).

The length and intensity of a contrail depends on the atmospheric conditions, aircraft type, and aircraft velocity. Typical contrails vary in length from five to 15 nautical miles (NM) and are generally a few hundred feet in diameter. Contrails usually occur between 25,000 and 60,000 feet in altitude and in very cold temperatures (below 40° C). In very cold climates such as the polar regions, contrails can form much closer to the earth's surface. In the equatorial climates, contrails may form only above 75,000 feet. How long contrails remain visible depends on the air density and turbulence available to disperse the ice crystals. Studies have indicated two approaches

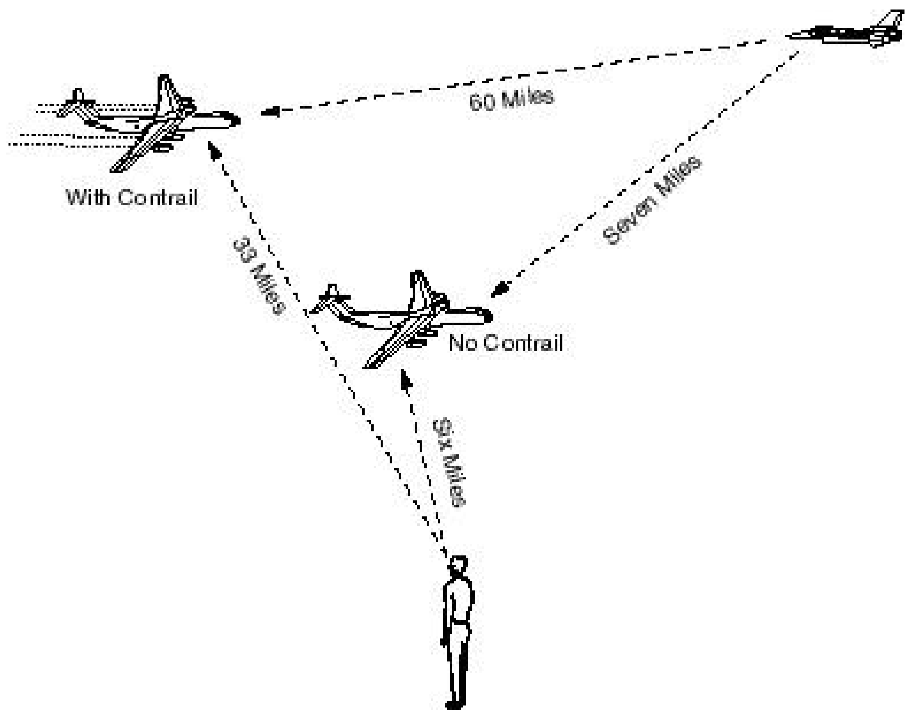



**Figure 27. Contrails as a Detection Factor**

to reducing or eliminating contrails. Since the quantity of water produced by the combustion of fuel is the most important factor in contrail formation, most efforts in this area are directed at fuel research. One approach is to reduce the amounts of water vapor produced in the combustion of fuel by using fuels low in hydrogen. A second approach is to reduce the size of the water vapor particles in the engine exhaust by adding chemicals to the exhaust plume. These chemicals will not only reduce the amount of water vapor exhausted but may also decrease the size of the water droplets, thus diminishing the amount of light reflected or refracted by the smaller ice crystals.[15]

### Canopy and Body Glint

Canopy and body glint occurs when sunlight is reflected in a narrow, concentrated viewing angle by windscreens, windows, glossy paint, and metallic surfaces. Canopy glint is a momentary cue that attracts an observer. It does not last long enough for target tracing or weapons employment. Glint is still a problem for LOPs because minimizing initial detection is almost as important as preventing weapons guidance. Curved windscreens reflect sunlight through a great number of viewing angles. These isotropic reflections contribute significantly to an aircraft's visual signature. The most effective technique to minimize canopy glint is to replace curved transparencies with clear, flat plates. While the flat transparencies will all have glint, the viewing angles of the reflection will be greatly reduced, thus limiting the possibilities for detection by observers. Using low-reflectance, lusterless paints can also reduce body or fuselage glint.

### Body Glare

Body glare is of a much lower intensity and is spread out over a greater viewing angle than glint. The application of lusterless paint will greatly reduce body glare.

### Exhaust Smoke

Reducing exhaust smoke is an important factor in minimizing detection of combat aircraft. Experience shows that large aircraft with old-technology turbojet engines can leave a smoke trail that is easily detectable 20 to 30 miles behind the lead aircraft. How long the smoke trail persists will depend on atmospheric turbulence or wind currents. Reducing exhaust smoke is a factor of engine efficiency and increasing combustion temperatures.

### Ground Shadows

Aircraft produce ground shadows when flying close to the ground. These shadows are easily detectable by airborne observers (table 6). Backgrounds that provide a high, uniform contrast are most likely to display a detectable shadow. Examples

**Table 6**

**Minimum Altitude for Ground-Shadow Avoidance**

| Aircraft Type | Aircraft Planform Area ($Ft^2$) | Minimum Altitude (Feet) vs. Solar Elevation | | | |
|---|---|---|---|---|---|
| | | 90° | 70° | 40° | 20° |
| Helicopter | 200 | 1,300 | 1,300 | 900 | 500 |
| Fighter | 800 | 2,300 | 2,200 | 1,900 | 1,000 |
| Bomber | 5,000 | 7,700 | 7,200 | 5,000 | 2,600 |
| Transport | 11,000 | 11,000 | 10,800 | 7,400 | 3,900 |

of these uniform backgrounds are dry lake beds, snow cover, and undercast or desert areas. Shadows result from direct illumination from the sun or bright moonlight on the aircraft. When these shadows fall upon a high-contrast background, an interceptor pilot can easily detect the presence of a penetrating aircraft.

## Miscellaneous Visual Signatures

Other important contributions to maintaining a low-visual profile come from minimizing the effect of the bright light and heavy smoke trail that results from launching weapons or firing guns, aircraft navigation and anticollision lights, and cockpit lights or helmet reflections. Randomly exposed openings such as speed-brake or flight-control wells and interiors should be painted with camouflaged or low-reflectance paints. These openings will contrast if painted a color different from the aircraft skin. Other surfaces such as the interior of the weapons-bay doors and air intakes should also be painted. Aircraft markings and insignias should be reduced in size and painted to match the general color and reflectance of the aircraft paint.

Decreasing the number of external stores is another important factor in maintaining a low-visual signature. Aircraft stores, such as fuel tanks, weapons, or mission support equipment should be carried internally. If this is not possible, then the stores should be carried conformally to minimize any increase in the visual size of the aircraft and any change in the shape of the fuselage. These conformal external stores should not produce right angles, high-contrast surfaces, nor easily detected shadows. Any external stores must be painted an appropriate color and reflectance factor to match that of the aircraft.

## Acoustic Detection

The major source of detectable noise from an aircraft is from its engine intakes and exhausts. Intake engine noise comes from the fan and compressor, while the exhaust noise comes from the fast-moving exhaust plume. Acoustic-reduction techniques employed by high-bypass turbofan engines produce minimum sound for the thrust available. The exhaust roar is minimized by the large, cool layer of bypass fan air surrounding the hot jet plume. Jet engine intake noise can be minimized with the application of "hush kits" that use sound-absorbing material and surface features in the intake construction.

### Notes

1. Fulvio Bessi and Francesco Zacca, "Introduction to Stealth," *Military Technology*, May 1989.
2. Doug Richardson, *Stealth: Deception, Evasion, and Concealment in the Air* (New York: Orion Books, 1989), 25–30.
3. Eugene F. Knott, *Radar Cross Section* (Dedham, Mass.: Artech House, Inc., 1985), 52.
4. Ibid., 30.
5. Nicholas C. Currie, *Techniques of Radar Reflectivity Measurement* (Norwood, Mass.: Artech House, Inc., 1989), 190.
6. Knott, 208.
7. Ibid., 419.
8. Ibid., 149, 267–69.
9. Richardson, 44.
10. Ibid., 42.
11. Knott, 258.
12. *The Camouflage Handbook*, AAFWAL-TR-86-1028 (Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories, 1986), chap. 1, 4–8.
13. Ibid., 17.
14. Ibid., 1.
15. Ibid., 1–12.

# *Glossary*

| | |
|---|---|
| AEF | air expeditionary force |
| AU | Air University |
| AWC | Air War College |
| $C^2$ | command and control |
| CADRE | College of Aerospace Doctrine, Research, and Education |
| CONUS | continental United States |
| CJCS | chairman of the Joint Chiefs of Staff |
| DOD | Department of Defense |
| dBsm | decibel square meters |
| ECM | electronic countermeasures |
| FSS | frequency selective surface |
| GHz | gigahertz |
| IADS | integrated air defense system |
| IR | infrared radiation |
| JFACC | joint force air component commander |
| JFC | joint force commander |
| *JV2010* | *Joint Vision 2010* |
| LO | low observable |
| LOP | low-observable penetrator |
| MHz | megahertz |
| $m^2$ | square meters |
| PGM | precision-guided munitions |

| | |
|---|---|
| NCA | National Command Authorities |
| NM | nautical miles |
| radar | radio detection and ranging |
| RAM | radar absorbent material |
| RCS | radar cross section |
| RCSR | radar cross section reduction |
| RMA | revolution in military affairs |
| SA | situation awareness |
| STW | surface traveling waves |
| UAV | uninhabited air vehicle |
| USAF | United States Air Force |
| US | United States |

**AirLand Battle.** The US military operational concept developed by the US Army and US Air Force to employ coordinated ground and airpower to defeat a Soviet and Warsaw Pact invasion of West Germany.

**circuit-analog absorber.** A radar-absorbing-material technique applied via special design of thin wires within the canopy structure. This grid of wires absorbs radar energy and prevents its transmission into and out of the aircraft cockpit.

**Desert Storm.** The coalition military operation, led by the United States with European, Asian, and Middle Eastern participation, that ejected Iraqi forces from Kuwait in January through March 1991.

**disproportionality.** The objective sense where a force can employ weapons in numbers and lethality in greater orders of magnitude than the opposing force is able to achieve. The resulting destruction is also far greater than that inflicted on us or expected by an adversary's political and military leadership.

**dominant battle-space knowledge.** A state of awareness that provides all militarily significant information in any theater we choose. It results from fusing real-time, all-weather information continuously and rapidly processed into usable knowledge and intelligence.

**dominant maneuver.** A JV2010 operational concept in which the multidimensional application of information engagement and mobility capabilities are used to position and employ widely dispersed joint forces to accomplish the assigned operational task.

**engagement hierarchy.** The tactical sequence used to find and engage penetrating aircraft in the following order: detection, correlation, tracking, weapon guidance, and warhead fusing.

**execution parameters.** Factors or attributes that describe an aircraft attack mission or sortie. These factors include routing to and from the target, timing requirements, target order/priority for multiple targets, and weapon choice/options.

**frequency selective surface.** An aircraft surface that is made up of certain geometric patterns whose purpose is to either prevent or allow transmission of specific radar frequencies through the surface material.

**gigahertz.** One billion cycles per second. A term used to describe the frequency of electromagnetic radiation such as radio or radar waves.

**glint.** A flash of reflected radar energy.

**integrated air defense system.** A defensive net that merges aircraft detection, interceptors, surface-to-air missiles, and antiaircraft artillery with command and control assets to detect, track, and engage penetrating aircraft into a protected airspace.

**joint force air component commander.** The military commander, chosen by the joint force commander, who plans, coordinates, and executes air operations in a specified area of responsibility.

**large-scale support.** Traditional force packaging where the strike aircraft are matched with fighter escort/sweep, suppression of enemy air defenses, stand-off jamming, airborne warning and control squadron, and the inherently large air refueling requirements. LOPs (i.e., F-117s) required minimum support against a dense and well-integrated Iraqi air defense net.

**megahertz.** One million cycles per second. A term used to describe the frequency of electromagnetic radiation such as radio or radar waves.

**parallel war.** A term introduced by Col John Warden that describes targeting across a spectrum of targets in a compressed time period. The goal is to simultaneously attack enemy centers of gravity across all levels of war (strategic, operational, and tactical) at rates faster than the enemy can repair and adapt to.

**passive attack.** An attack that decoys, deceives, and degrades an integrated air defense system by smart employment of LO signature management where you permit detection of your aircraft at a place and time of your own choosing followed by recloaking and escape.

**precision engagement.** A JV2010 operational concept that consists of target locations, effective command and control, accurate weapons delivery, and efficient weapons effects.

**radar.** A method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of very high frequency radio waves reflected from their surfaces.

**radar cross section.** The measure of an object's ability to reflect incident radar energy back to the transmitting site. RCS is expressed in terms of area and in units of square meters or decibels above or below one square meter (see table 3).

**radar cross section reduction.** A process in which the RCS of an object is reduced by shaping, using radar-absorbing materials, and passive and active cancellation of incident radar energy.

**reflectance.** The measurement of how much or what percentage of ambient environmental light is reflected by a certain material—natural or man-made. A high-reflectance surface or color is glossy and a low-reflectance surface is dull and lusterless.

**revolution in military affairs.** A recent term that describes the concept in which militaries fundamentally change both their concept of operations and their organization structures to best employ radically new technologies. An RMA gives us a superior set of military strengths that are not available to other competitors.

**scintillation.** The sparkling of a radar return due to mutual interference phasing of the radar reflections.

**signature.** The telltale characteristics of a particular object that gives away its presence (e.g., radar, self-generated electronic emissions, infrared, visual, and acoustic).

**signature management.** The ability to limit enemy awareness of your location, routing, and intentions. Signature management can be obtained by a combination of aircraft characteristics, mission planning, and in-flight tactics.

**situation awareness.** The tactical state where the aircrew maintains knowledge of enemy location/intentions and their own aircraft status and performance.

**surface traveling waves.** Type of reflected radar wave that strikes an object at a near-grazing angle and travels along the surface. Once reaching the end of the object or upon encountering a surface discontinuity, the wave will split into two waves of equal magnitude, but opposite directions.

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