8 — ADVANCES IN FIGHTER TECHNOLOGY

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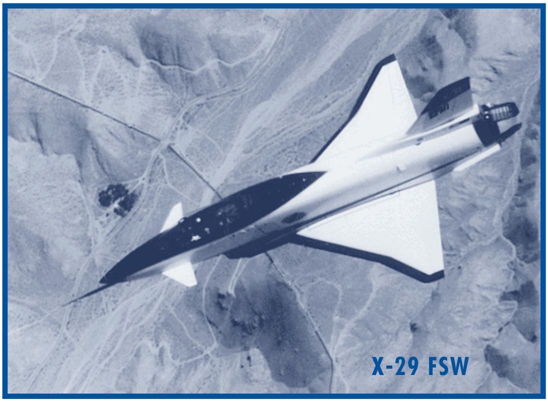

X-29 FSW

World War II proved to every military power that well-trained pilots are a crucial element in the war to win the skies. Since then, fighters have become extremely complicated requiring millions of dollars to build and thousands of hours to master their complexity. Nevertheless, one simple axiom has remained constant and often predicts the outcome of an air battle — *Speed is Life*. This lesson has been taught in every conflict to date. Maneuverability is almost as important. A lack of maneuverability in American aircraft became painfully evident during the **Korean** conflict, the first major air war fought extensively with jet-powered aircraft. Even though the F-86 Sabre (the premier U.S. fighter at the time) was a superior aircraft speed-wise, its turning ability was inferior to that of the MiG-15. Yet despite an inferior turn rate and radius, American pilots were still successful in Korea, further reinforcing the importance of a pilot's skill. The conflict also taught aircraft designers lessons about tradeoffs between speed and agility.

In **Vietnam**, the initial assumption was made that air battles would be fought beyond visual range, with guided missiles that would obviate the need for dogfighting and agile flying. But before the conflict ended, it became apparent that missile combat could still occur within visual range, and that guns-only dogfighting was still common.

Desert Storm proved the effectiveness of reduced radar visibility in the stealthy F-117A Night Hawk, the undisputed star of that conflict. In the opening attack, the F-117 fighters remained undetected as they penetrated the very heart of Baghdad under the cover of night.

Advancements in stealth and other aspects of aircraft technology in the last century are proof of exponential growth in the industry. Aside from training, the outcome of an air battle is determined by agility, speed, stealth and sensors. *Fighters Anthology* examines the hardware designs that focus on these traits. What remains to be discovered are the advantages that will be gained, and the trade-offs that will be made, as these aircraft are tested in combat with and against conventional and advanced-technology fighters.

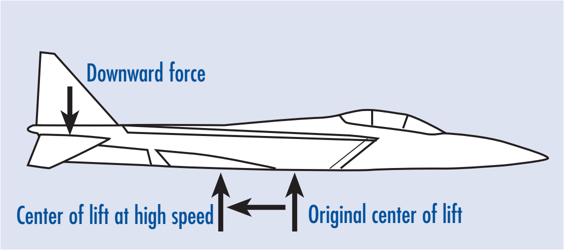
AGILITY

The agility of an aircraft is defined by its ability to perform maneuvers within certain speed, G-load, distance and time parameters. Superior agility allows a pilot to point and shoot at his target more easily, and it allows rapid transitions in motion that a) are unpredictable to pursuers, and b) give the pilot more time for making decisions.

Several techniques have been developed for enhancing the agility of modern fighter aircraft. Fighters moving at high speeds tend to be very stable, which translates into less agility. At higher speeds the center of lift of the aircraft moves backward along the wing. This happens because more air passes over the aft horizontal surfaces and creates more "downward" pressure on the rear of the plane. The strength of this force depends both on speed and angle-of-attack (AoA). The total effect is similar to that of the rear fletching on an arrow.

In flight, the aircraft becomes more and more stable (thus, less maneuverable) as the center of lift moves rearward. To make an aircraft more agile, it can be designed so that the center of lift, even at high speed, is still relatively far forward. However, the price of this design is that at lower speeds, the plane has an aerodynamic tendency to swap ends (reverse nose and tail positions).

No human pilot is skilled enough to fly such an unstable aircraft design effectively in combat. But, a computer with lighting-fast sensors that determine an aircraft's position at any given moment *can* perform this function. The pilot supplies control inputs, which send digital instructions to the computer. The computer can then apply the correct inputs to guide the plane through the intended course, all the while making thousands of minute corrections to the aircraft to keep it on that flight path. The result of this computerized design is an aircraft with incredible performance characteristics.



Fly-By-Wire (FBW) Control System

Conventional flight controls use hydraulic fluid to transfer a pilot's control inputs to the appropriate control surfaces. In the 1970s, research began on *fly-by-wire (FBW)* technology, a computerized flight system that relies on computers, wires and sensors. The main difference between the two systems is that fly-by-wire transfers pilot inputs to an electronic signal instead of into a hydraulic medium. When the pilot moves the stick, it sends a command to the flight control computer. The processor then calculates the exact adjustment needed and sends a signal to the actuator to move the control surface.

The FBW system does much more than just transfer the pilot's command to the flight surface. It also receives input concerning flight conditions, such as speed, altitude and attitude. The computer assesses all of this information and continuously adjusts flight surfaces (up to 40 times per second) even when the pilot is not sending commands to the processor. When inputs are sent, the FBW system takes into account flight parameters and coordinates that information with the pilot's commands. The result is that the pilot's inputs are semi-corrected before action signals are sent to the plane's control surfaces.

FBW systems are not foolproof; they are susceptible to nuclear disruptions, jamming and other powerful electronic conditions. All FBW systems are backed up by three independently powered computer systems, all of which have their own analog backup.

In the last few years, *fly-by-light* technology has made its debut, and will likely replace FBW in new 21st century fighters. Its principle of operation is the same, only its "wires" consist of fiber-optic cables that send pulses of light to a control actuator. This speed-of-light technology is impervious to disruptions that can affect current FBW systems.

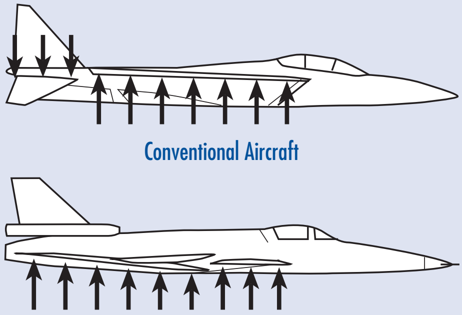
Tailless Aircraft

The addition of canards has nearly eliminated the need for the horizontal tailplane (flat tail structure) and its tailerons (flap/aileron structures). This should not be confused with the vertical tail rudder, which is still a prevalent structure on any fighter (although testing with the XF-31 includes the gradual removal of the rudder). One drawback to the tailless design is that when taking off and landing, the main wing elevons — movable, trailing edge surfaces that provide lift — must struggle to both control pitch and maintain sufficient lift.

Without canards, elevons on tailless craft must angle upward on takeoff to pitch the nose up. This effectively adds a downward force at the rear of the wings, which in turn requires more upward force for liftoff. On planes *with* canards, the lift provided near the front of the plane alleviates some of this force, and the elevons are angled less steeply. This allows the elevons to provide lift instead of downward force.

Relaxed Static Stability

Tailless aircraft are aerodynamically efficient during flight — they experience less drag and better maneuverability, and consume less fuel than normal planes. However, they tend to be unstable during flight. An aircraft's *stability* is its tendency to return to level flight after a control change.



Conventional Aircraft

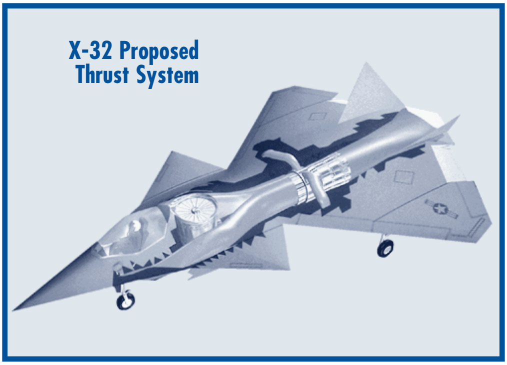
Forward Swept Wing X-29 with Canards

In conventional aircraft, the tailplane continuously applies a downward load that counteracts lift produced when control surfaces are moved (see diagram). Lacking such a rear stabilizer, tailless fighters are difficult to control at subsonic speeds. This intrinsic trait is called *relaxed static stability*. Modern FBW flight control systems are designed to provide artificial stability for fighters built with relaxed static stability.

Thrust Vectoring

Another technique that increases an aircraft's agility is to use the engine to reorient the nose of the aircraft by actually changing the direction of the thrust, called *thrust vectoring*. This is accomplished by moving engine exhaust paddles, vanes or the entire exhaust nozzle to redirect the flow of the exhaust gases. This creates a rotational force on the aircraft. Usually, a small angle (-30° to +30°) is sufficient to give an extreme, controlled change in pitch.

Vectoring permits sharp, controlled turns that are impossible in older fighters. The advent of thrust vectoring allows the pilot to point his nose at the target more easily, and has given birth to new flight maneuvers, the most notable of which is the Herbst maneuver (see **Herbst Angle-of-Attack Maneuver**, p. 155).



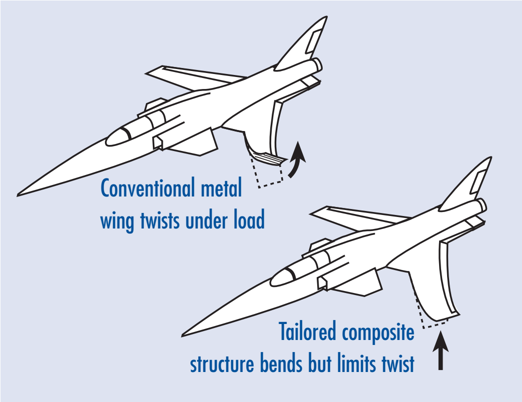
The F-22 vectors on one axis, allowing the nose of the aircraft to pitch up or down. The X-31, on the other hand, uses a two-axis system that allows both vertical pitch and horizontal yaw. Some aircraft — such as the AV-8B Harrier and Sea Harrier — have nozzles that angle 90° or more for nearly vertical take-offs and landings. The current design for the X-32 utilizes flaps to redirect engine thrust up or down, and incorporates a lift fan that allows ASTOVL (Advanced Short Takeoff and Vertical Landing) capabilities.

As proven against normal fighters, aircraft that use thrust vectoring have a greater chance of surviving in actual combat. They can make short, quick turns to bring an enemy into their weapons envelope, perform sharp evasive maneuvers in a fight, and perform post-stall turns without losing control of flight surfaces.

Another advancement due to vectoring is the nearly vertical operation of the ASTOVL and Harrier fighters. Both use the rear engine and a second set of engines to quickly accelerate and decelerate on short runways, and the angles of thrust typically surpass the 90° mark. The Harrier possesses the unique ability to change direction or maintain a hover in midair by collectively angling its thrust. Using its four exhaust nozzles, it can provide lift, thrust, or lift and reverse thrust. In the future, it is almost certain that all fighters will employ some sort of vectoring mechanism.

Composites

Fighters were originally built with wooden wings and fuselage structures, then with metallic compounds and aluminum. Over the last decade, material engineers at Flight Dynamics Laboratory discovered that plastic or resin materials could be reinforced with other fibrous materials to create strong, lightweight materials called *composites*.



Composite materials are not rigid — the carbon, glass, Kevlar, other fibers or metallic oxide particles are arranged and embedded in plastic in a process called "aeroelastic tailoring." This means that the material will remain rigid in one direction and bend in another when certain aerodynamic forces act on it. The composite is strengthened by layering composite fabrics over a casting mold and then heating the entire assembly.

All new fighters take advantage of composites, which deliver great structural value at a lower weight and overcome the plaguing problem of structural divergence. (This is the tendency of the wing to bend up and back during high-speed flight.) Not only is this new material lightweight, but it also allows the wing surface to be manufactured as a single piece.

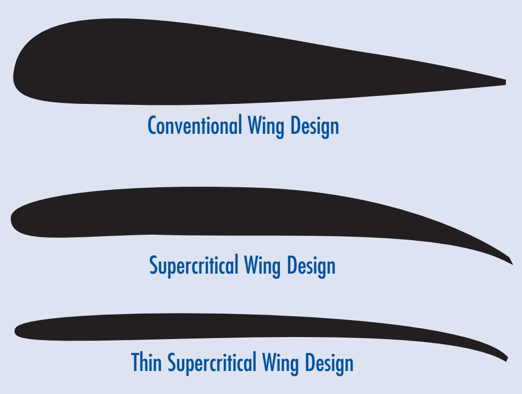
The development of composite materials was the sorely needed technological leap that allowed the Forward-Swept Wing (FSW) fighter to be developed (see facing page). Although the design has been around since the 1950s, no structural materials were previously available that could withstand the twisting forces this structure generates during flight. Now that composites are regularly used in aircraft production, new wing designs like the FSW can be tested.

As composites continue to evolve, they will certainly become more and more integral to aircraft design. Present aircraft use as much as 50 percent composite materials in production, reducing size, weight, drag and fuel consumption. Recently, other applications for composites have come to light as well — one type incorporates electromagnetic "pockets" designed to dissipate incoming radar. (See **Radar**, p. 233, for more information.)

Composites are also being researched that will reduce an aircraft's infrared signature. With the threat of modern IR weapons, minimizing the outside temperature or "skin" of the aircraft is obviously important. Composite research concentrates on this, and the search for insulating materials is never-ending.

Supercritical Wing

As mentioned earlier, air passing over an airfoil (wing) surface is what creates lift. The air traveling over the top of the wing is moving faster than the air moving under the bottom surface of the wing. This difference in speed also results in a difference in pressure between the underside and top of the wing, which creates the upward force called lift. When a fighter approaches the sound barrier, however, shock waves form on the wing and disrupt this flow of air over the wing.

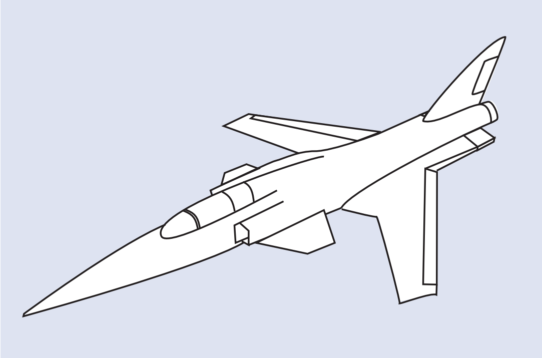


Researchers have known for several decades that a thinner wing lessens the shock wave effect, but building such a wing was impractical before composite materials were developed. Nowadays, the supercritical wing is both useful and possible. The F-8A was the first aircraft to use the supercritical wing, but now it is a common design for all types of planes.

The cross-section of a supercritical wing is thinner than that of conventional wings, and the upper surface is flatter. The back edge of the wing is curved, while the front is blunt. This lessens the effect of air buffeting and drag during high-speed flight. These characteristics require less power and allow better maneuverability, higher top speeds and increased range.

The newest development in this wing design is the thin supercritical wing, a flatter version of the normal design. The X-29 is the first fighter to test such a wing.

Forward-Swept Wing (X-29 only)

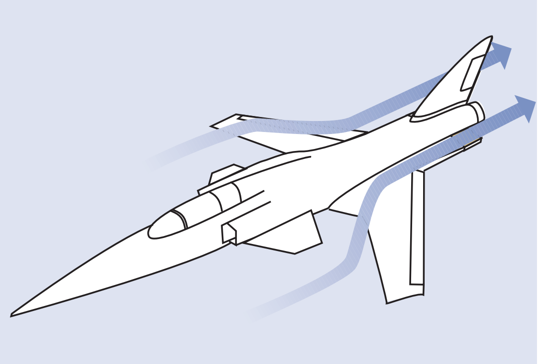


The concept of forward-swept wings (wings angled forward instead of backward) has been around since World War II, when it was explored by Germany. However, until composite materials provided the material strength needed, all experiments of this type resulted in the wings ripping almost immediately during a turn due to a twisting, aerodynamic force.

With its composite structure, the forward-swept wing overcomes such trivial problems as structural divergence (the twisting force mentioned earlier). Instead, it offers a number of positive flight characteristics — it reduces drag by 29 percent, uses less fuel, reduces stall probability, provides enhanced maneuverability, and allows a maximum airspeed of 800 mph. Currently, the X-29 fighter is the only aircraft to utilize this wing configuration. No production fighter has yet incorporated the FSW into final design.

Unquestionably, the most outstanding feature of an FSW is its increased *angle of attack* (see **Appendix B, Glossary of Terms**). At 45°, the new X-29 fighter maintains agility; at 60°, it is still controllable.

The high AoA and low stalling speed of the X-29 are possible because of the reverse airflow caused by the wing configuration. Air flowing over a conventional wing flows outward toward the wingtip. In FSWs, air tends to flow inward toward the base of the wing. This means that the airflow over the wingtips remains smooth, giving the aircraft increased maneuverability. Any stalls that do occur begin at the base of the wing (away from the aileron control surfaces) and are more controllable.

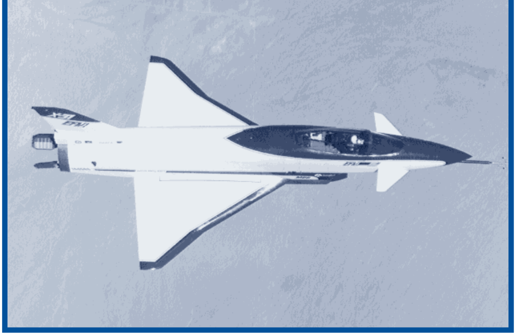


Pitch on the only existing FSW fighter is controlled by a trio of flight surfaces — canards, ailerons and thrust-vectoring vanes. The pair of adjustable canards can move -60° to +30° from horizontal, sharing the aerodynamic load of the main wing and providing some pitch control. The main FSW wings use a set of *flaperons* (flaps/ailerons) to control pitch and roll. Finally, the rear engine has two "strake flaps" that control the majority of the aircraft's pitch.

One disadvantage to forward-swept wings, some say, is that the protruding wing configuration compromises stealth under enemy radar conditions. A second drawback to the X-29 is that it is the most unstable of any of the current *fly-by-wire* (computer-controlled) aircraft. The center of gravity of the aircraft is *behind* the center of lift at speeds less than Mach 1, making it rear-heavy at low speeds. As the aircraft speeds up to Mach 1, the center of lift moves backward and more or less coincides with the center of gravity. At this point, the aircraft is "balanced" in flight and the wings operate much more efficiently.

Close-Coupled Canards

X-31 EFM with canards



Canards, or foreplanes, are small wing-like structures mounted forward of the main wing that act as pitch mechanisms and horizontal stabilizers. In previous production planes, elevators on the tail structures performed these two functions but added extra drag to the aircraft. The addition of canards in front of the wings solved the drag problem and introduced several advantages.

The latest canard designs are "close-coupled," meaning that the canards lie in the same horizontal plane as the main wings. This spreads the aerodynamic load between the two wing surfaces and redirects airflow vortices (swirling currents of air). The vortices created by the canards pass over the outer surfaces of the main wings, adding more energy (in the form of moving air) to the wings and preventing the boundary layer of air over the wing from growing "sluggish." They also prevent aerodynamic stalling at the wing base on forward-swept wing fighters. The actual geometry is complicated, but the end result is additional maneuverability in circumstances where control surfaces in non-canard aircraft would stall.

One distinguishing characteristic of canards is their variable-incidence capability, or the ability to rotate up and down from a horizontal position. Although some models employ fixed canards, most new fighters are taking advantage of canards as adjustable control surfaces. On the Grumman X-29, the canard surface represents a fifth of the total wing area and can move from 60° down to 30° up. In a tactical sense, this means the pilot can pitch the nose of the plane up or down by changing the angle of the canards. This applies angled lift forces near the front of the plane and greatly increases the turn capability and maneuverability of the fighter, especially at high speeds.

SPEED

Speed is the very essence of air combat. It can be transformed into altitude, and vice-versa, to gain the advantage in battle. More often than not, whoever has the most speed when a fight is initiated holds the upper hand. What determines an aircraft's speed is its engine power. And as aircraft designs continue to improve, so does engine technology.

Test version of the F-22A

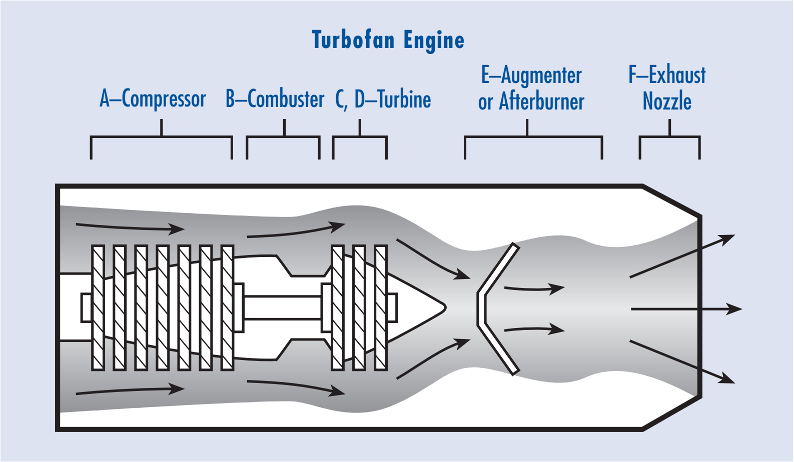
Engine Technology

Thrust is the force that propels an aircraft through the air. It is generated by an aircraft's engines, also called power plants. The more power a fighter's engine can muster, the faster the plane can accelerate. The quest for speed has been a prime factor in aircraft design for decades, and the problem of how to sustain supersonic flight without afterburning has been a plaguing problem until recently.

Modern aircraft engines strive to meet the strict requirements of high thrust, high temperature limits, low weight, low fuel consumption, and tight manufacturing tolerances. Therefore, the manufacturing race is to develop an engine that is lighter and more powerful than its counterparts.

The propulsion power of an engine is referred to as its *thrust-to-weight ratio*. This compares the amount of thrust that can be generated to the total weight of the aircraft. The higher this ratio, the more powerful the engine. The average thrust-to-weight ratio for most fighter planes is 0.8. Newer combat craft surpass 1.0 and thus have enough power to climb vertically.

A *turbofan* engine produces power by passing external air into the engine, moving it through several stages, and igniting a fuel-air mixture to generate thrust (see below). Called turbo combustion, this creates intense heat (approximately 1,800° to 2,500° F). New alloys have had to be developed to withstand these high temperatures. Nickel alloys are most common — they can be cast and specially cooled as single, crystalline pieces free of structural weaknesses.



How a Turbofan Engine Works

A) Air is sucked into the engine and compressed in stages by turbine blades.

B) Compressed air is mixed with fuel and injected into a combustion chamber.

C) The resulting hot gases (1,800° to 2,500° F) travel through a nozzle into the turbine and drive turbine blades.

D) The turbine blade wheel turns a second compressor that further compacts the gases.

E) The gases escape out the exhaust nozzle and propel the aircraft.

F) Additional fuel can be injected into the exhaust for short afterburner bursts.

The amount of pressure exerted by the escaping gases are the heart of the engine's power. The higher the pressure, the faster the gases pass through the exhaust nozzle. For this reason, engineers developed a spinoff of the turbofan engine called a *turbojet* engine. The principles are the same, except that the turbojet only allows a small amount of air into the compression chamber. The remaining air "bypasses" the engine via a bypass duct.

The bypass duct limits the amount of air that passes through the engine. This creates more pressure in the same volume of space (previously occupied by more air in turbofan engines). The amount of air entering into the engine ranges from 3 to 50 percent of the total air used; the rest is fed into the bypass. This type of engine features more efficient fuel combustion, lower smoke production, and lighter weight.

For aircraft that spend most of their time flying supersonically, the turbojet is a competitive engine. The turbofan combustion engine, however, has become the common choice for fighters that fly at subsonic speeds. The Pratt & Whitney F100-PW-229 model is a popular choice on many fighters currently in service, allowing aircraft to climb vertically with its nearly 30,000 pounds of thrust.

ATF Engine Requirements

Specifications for advanced tactical fighters call for the ability to provide afterburner bursts, and some (like the F-22) will be required to cruise in supersonic flight. Recent, more powerful engines have surfaced in the F119-PW-100 version of the Pratt & Whitney turbofan and the Rolls Royce Pegasus. Of the two, the F119 most closely resembles a turbojet engine, bypassing only enough air to cool the afterburner chamber (this is more effective for supersonic flight). A common factor between the two engines is that they support thrust vectoring, described earlier (p. 221).

In the still-classified Joint Attack and Strike Fighter (JAST) program, even more powerful engines are being called for that can accelerate to and cruise at supersonic speeds without relying on afterburners at all. Non-afterburning aircraft have smaller radar signatures and conserve fuel.

STEALTH

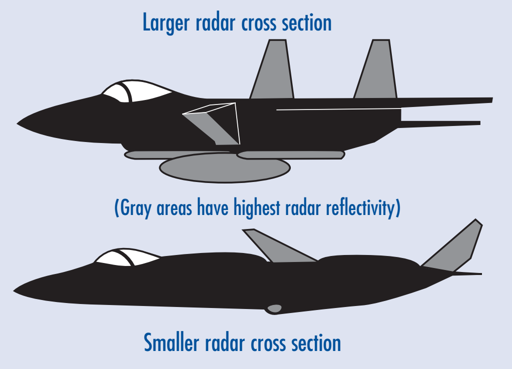
B-2A Spirit Bomber

Now that long-range weapons have lessened the need for up-close bomb and missile runs, research concentration has shifted toward one question — how to approach the enemy unseen. Remaining undetected is the fighter pilot's greatest challenge, whether conducting an offensive attack or returning to base with valuable reconnaissance information.

Stealth technology as we know it today dates back to the 1950s, when the Defense Advanced Research Projects Agency (DARPA) funded secret Lockheed research to explore radar evasion techniques. The first "Have Blue" prototypes were originally painted in camouflage to conceal contours, then in light gray. Later came the F-117, which was plastered with polygonal surfaces designed to reflect radar waves away from their point of origin.

Stealth avoidance involves more than avoiding radar, however. Seven detectable signatures are given off by aircraft: radar, infrared, visual, engine smoke, electromagnetic emissions, acoustics and vapor trails. Today's stealth-driven research concentrates on reducing radar, infrared and EM emissions. This can be done by carefully designing the aircraft's exterior, reducing its radar signature, shielding its "hot spots," and covering the exterior with radar-absorbent, composite materials.

Radar Cross-Section (RCS)



The first approach to making a plane stealthy is to make it as invisible as possible to enemy radar systems. By virtue of design, aircraft are natural reflectors of radar. Inlet edges, spinning blades, tall tails, rudders and joints readily return all beams to their source. Together, they give an aircraft a radar signature, or "picture" that the aircraft reflects when struck by a radar beam.

The size of this signature is called a *radar cross-section*, and varies according to the aircraft's shape. The larger the RCS, the more deadly enemy radar-guided missiles become — their seeker heads use radar returns to home in for the kill.

RCS is figured through complicated measurements that depend upon the size of the physical cross-section, how reflective the plane's surface is, and in what direction the reflection is returned. Oddly enough, the physical cross-section is not as important as reflectivity — some planes have smaller radar cross-sections than a small mammal. The resulting RCS is measured in square feet.

Logically, aeronautical engineers seek to minimize the size of the RCS during the design process of any aircraft. Flat, vertical surfaces tend to reflect radar beams directly back to the source; therefore, the height of the plane and tail are vital. Sharp corners also give away an aircraft's presence to enemy radar systems.

The best fighter designs exhibit many faceted surfaces (flat, angular panels) and curved joints (transitional surfaces that blend into one another). The first deflects radar beams away from their source of origin; the second gently guides radar beams around the aircraft's surface.

RAM/RAS Surfacing

Planform shaping (designing the aircraft with rounded edges and angled panels) reduces an aircraft's radar cross-section considerably. But although changing the shape of the aircraft helps reduce its RCS, it doesn't eliminate it. Other methods are also applied to reduce the likelihood of detection by radar. A relatively new advancement in stealth technology is the development of *radar-absorbent materials* (*RAM*) and *radar-absorbent structures* (*RAS*).

Radar-Absorbent Material (RAM)

A new type of composite material, RAM contains thousands of absorbent pockets. It receives radar beams and converts their energy into heat or small electromagnetic fields. The actual process is highly complicated, but is simple in principle. When a radar beam hits the plane's outer skin, it enters the ferromagnetic pockets. These pockets bounce the beams back and forth between other pockets in a chain-link process. Eventually, the beam loses its intensity — and its effective radar echo.

Although not all beams are dissipated in this manner, enough are absorbed to give the aircraft additional stealthiness. A fighter with a small RCS and a composite RAM skin can effectively pierce an enemy's defenses and not be detected until it has almost reached the target.

Radar-Absorbent Structures (RAS)

RAM material does not entirely cover a fighter's exterior. Instead, angles and planform shaping are used to reduce the RCS as much as possible. For areas that are still problematic, engineers add RAM. Where additional stealthiness is needed, they add RAS (radar-absorbing structures). These structures are hollow, radar-transparent plastics that are filled with additional RAM material.

RASs are usually reserved for use on stealth-specific aircraft, where joints, inlets and control surfaces give away the plane's position on radar. Recently developed RASs can absorb almost all of the radar energy that strikes them. Radar-absorbent paint, nicknamed "Iron Ball," is also applied to stealth bombers and fighters to ensure near-invisibility to radar at certain minimum ranges.

Intake and Exhaust Concealment

Radar (RAdio Detecting And Ranging) is the most common method of detection. Second to it is infrared tracking, which picks up "heat signatures" given off by objects. The frequency of IR waves are higher than those used by radar and fall just below the end of the visible spectrum. Just like radar-guided missiles, certain seeker heads use infrared search techniques.

These infrared missiles are dangerous to fighter pilots because their tracking mechanisms are not directly related to radar. The aircraft's RCS does nothing to conceal its infrared signature. Although the firing party originally detected and acquired the fighter as its target using radar, the heat-seeking IR missile is equipped with a seeker head that can detect "hot spots." It scans an arc in front of its flight path and searches for the best heat source at a wavelength that matches that of the intended target's radiation.

The two "visible" IR wavelengths fall between 2 and 5 microns (given off by jet engines), and 8-15 microns (given off by friction or solar heating). The first wavelength is hotter; therefore, the most likely targets for an IR missile are exhaust ports and hot engine casings. For this reason, aircraft designers spend a lot of time and money ensuring that these areas are shielded and cooled as much as possible. Some modern fighters feature the exhaust port on top of the wing or fuselage to shield it from IR missiles with altitudes lower than that of the aircraft.

Cooling the air that flows from an aircraft's exhaust pipes is a continual problem. Bypass intakes that mix outside air in with exhaust gases are standard. On newer fighters, the intakes and nozzles are often placed so that exiting exhaust flows around the rear of the fuselage, which acts as a "screen" against IR missiles. Engineers are also testing injector systems that intersperse cold chemicals (like chloro-fluoro sulphonic acid) with hot exhaust.

WEAPONS/SENSOR TECHNOLOGY

External sensors, internal camera and detection systems, multi-functional displays, and onboard computers compose an aircraft's *avionic* system. Two vital functions of avionics are to transfer some of the pilot's workload to a computerized system and to make the job of finding/targeting enemies easier. The bulk of enemy detection is carried by two major sensor systems — radar and IR (Infrared).

Radar

The first of the sensor systems is radar, whose name is derived from *RAdio Detecting And Ranging*. Although radar has evolved since the 1940s, its function — detection — has remained constant. It is used by virtually every non-transport military vehicle in some form or fashion, and is the foundation for self-guided weapon technology.

Radar is fairly simple in concept: concentrated pulses of short-wave radio waves are sent in a general direction, and their echoes are "read" on a radarscope. Radar pulses are fed through an antenna at various frequencies, allowing the antenna to act as a receiver between pulses. (Changing the frequency after each pulse is called *frequency modulation ranging*, and gives an identifying label to returning echoes.) Any objects in the path of the radar beam reflect back echo signatures that display as blips on the screen. By reading the intensity and elapsed time of the returning radar beam, the radarscope can identify a target's approximate distance and speed of travel.

While early radar systems had a single function (such as detecting air targets or mapping terrain), present-day systems possess multi-mode capabilities. The APG-70 is one of the most modern radars in use, with the ability to simultaneously track multiple air targets, distinguish between friends and foes, collect target speeds and geographical information, and supply information to help the pilot guide his weapons.

The APG-70 uses different pulse-repetition frequencies, or pulse rates, to provide either medium (10,000 pulses/second) or high radar resolution (300,000 pulses/second). Slower intervals give the radar more accuracy and have less margin for error — pulse echoes arrive back before new ones are sent, resolving any ambiguity that might result from multiple pulses.

The APG-70 allows target verification even when the target is outside visual range. This is known as Non-Cooperative Target Recognition (NCTR), which "questions" transponders on detected aircraft. The system is far from perfect, however, and pilots still prefer to obtain visual IDs before firing. The APG-70 uses varying levels of frequencies and power levels to defeat enemy RWRs and other ECMs and has built-in trouble-shooting software.

IN A HURRY
MULTI-PLAYER
GROUND
COCKPIT
COMBAT
CAMPAIGNS
PRO MISSIONS
TECHNOLOGY
SPECS

Advanced Tactical Fighters Avionics

Future generation fighters (such as the F-22) will incorporate an advanced avionics system that links all of its sensors and onboard systems through a local area network. The radar used is the APG-77, a system that uses a number of modular mini-radars. Contrary to the high-energy emissions given off by normal radars, each of the modules emits low-energy pulses that are spread over a wide set of frequencies. Conventional radar warning systems don't have the ability to detect pulses within the APG-77's range, giving the F-22 an extreme offensive advantage. Another benefit provided by this new radar is that each mini-radar can independently conduct its own scan. This reduces scanning time from 15-plus seconds to milliseconds. Finally, the NCTR software upgrade delivers more accurate screen information concerning friendly and enemy targets.

IR (Infrared)

Although radar remains the primary sensor on fighters, infrared sensors are a valuable tool for attacking both air and ground targets. IR systems detect radiated heat emitted by objects and present it as a visual, onscreen image. Two major infrared sensors exist: IR (Infrared) and IRST (Infrared Seeker Tracker). Both operate by sensing heat sources.

IR systems are similar to infrared television systems, and can have either a wide-angle sensor or a narrow field-of-view sensor. The assembly is mounted in a pod or turret, and has several detection cameras that can transmit independent views. The camera sensors detect sources of heat and send this information to a computer, which in turn translates the different temperatures into a visual image. With a trained eye, a pilot can pick out targets from the "clutter" that is emitted by trivial objects.

Often, an IR system is incorporated into a navigational system, such as the Low-Altitude Navigation and targeting Infrared Night (LANTIRN) system used on the F-16, or the AAQ-14 Navigational pod. IR is especially well-adapted for ground mapping and other navigational procedures, although it can also be valuable in isolating ground targets (as proven by F-111s during Desert Storm).

IRSTs operate in wide-angle view and are usually dedicated to painting air targets that are anywhere from 10-15 nautical miles out. These systems operate along medium-to-high IR wavelengths and utilize a stabilizer sensor that takes the source aircraft's movement into account. Like FLIRs, they are pod-mounted and feed information to an onboard digital display.

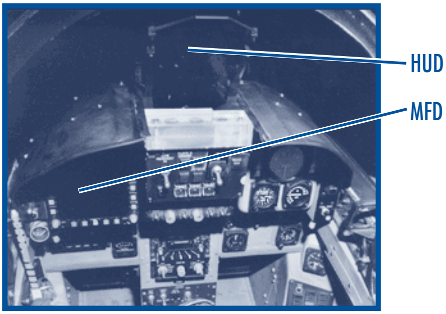
Radar and Infrared Seekers

Advancements in radar and IR technology are not singularly applicable to aircraft and ground systems. A highly valuable use for both has surfaced in the form of guided bombs and missiles equipped with seeker heads. Guidance technology is not new, but conventional methods require that the pilot keep the tracking system trained on the target until impact.

This is not the case with seeker-equipped weapons; their tracking sensors are built directly into the weapon itself — the seeker head is essentially a miniature version of a radar or infrared system. The only task for the firing aircraft is to feed the position, course, present heading and speed of the target to the AI system in the missile's nose. Once the missile fires, it flies out some predetermined distance and then switches on its own homing system. The seeker identifies the target, queries it for friend-or-foe, then locks on for detonation. This gives the pilot true "fire-and-forget" capability, meaning that he can fire off one weapon and immediately concentrate on a new target.

The first "fire-and-forget" missile was the AIM-54 Phoenix, which was initially used on the F-14 Tomcat and is still in service today. The AIM-120 (first put into service on the F-15) was originally tested in 1992 and has earned the nickname "Slammer" by the pilots that use it. A newer model of the AIM-9 Sidewinder (the AIM-9X) is in the works, and future generations will likely incorporate thrust vectoring and more powerful propulsion systems.

HUDs and MFDs



Over the last decade, weapon and computer advancements have cluttered fighter cockpits with a formidable array of switches, dials and other mechanisms. Once computer processors and software became powerful enough to handle some of this information, many of these cockpit controls moved to electronic displays. Arguably the most important development in fighter history is the development of the *Head-Up Display* (HUD) and the *Multi-Functional Display* (MFD).

Head-Up Display (HUD)

The HUD is currently a transparent screen placed in the cockpit, right in the middle of the pilot's view. Information from the aircraft's various sensors is transmitted to the onboard computer. Important items, such as airspeed, target cues, weapon indicators and navigational information, are projected onto the HUD with neon-green imagery. Current research involves a similar helmet-mounted sight capable of slewing any direction, a development that is already being used by the AH-64D Apache Longbow helicopter.

For a description of HUD information, refer to **Head-Up Display**, p. 77.

Multi-Functional Display (MFD)

Operating cooperatively with the HUD are the Multi-Functional Displays, or LCD computer screens mounted in the cockpit. Most modern fighters use two, although it is probably safe to assume that three or more will be used in future generation aircraft.

By selecting "mode" buttons around the perimeter of each screen, the pilot can display different information provided by the aircraft's systems. Most MFDs have several modes that give radar, navigational and targeting information; the scope of MFD information is too broad to list here.

For a complete description of MFDs used in *Fighters Anthology*, refer to **Instrument Display Windows**, p. 88.

ELECTRONIC COUNTERMEASURES

Avoiding detection is only the first step in stealth technology. No matter how stealthy it is, an aircraft becomes vulnerable to detection when it flies close enough to a target. Fighters need to know when they're being tracked by radar, and they need methods to defend themselves when under attack. For these purposes, engineers have developed defensive devices called *countermeasures*.

As modern warfare becomes more technologically driven and electronic in nature, electronic countermeasures (ECMs) become increasingly important. Types-to-date include radar warning receivers and electronic jammers (discussed here), which accompany traditional flare and chaff countermeasures (discussed in **Defenses and Countermeasures**, p. 130).

Radar Warning Receiver

The radar warning receiver is a passive device, meaning it does not emit anything that betrays the aircraft's presence. It is a standard member of every fighter's electronic system and consists of external sensors that feed information to a digital processor in the onboard computer. The sensor receivers can appear in retractable antennae form (to reduce RCS) or can be mounted in pods on the wings and tail. When its sensors detect radar beams, it analyzes them and displays information concerning the emitter. Although it is impossible to cover 360° up, down and around the aircraft, the RWR can detect most radar threats.

With radar beams emanating from the ground, friendly forces, enemy targets, SAMs and the aircraft itself, the RWR's most daunting task is how to single out threatening transmissions. The radar warning receiver is programmed to detect and observe the most imminent radar threats. It does so by analyzing the pulse-repetition frequency of the radar beam. A distant SAM site, for instance, will have a weaker, slower emission than an approaching missile with a radar-seeker head. Today's complex processors store radar signatures in a threat library and can often give the emitter's direction, class and range in a split second.

Note: *IRWR models (infrared warning receivers) accomplish nearly the same thing by using optical, infrared sensors. However, they are normally employed as ground-based systems that act as early missile warning sites.*

Once it detects and identifies an emission, the RWR "observes" the threat and watches to see how it responds to jamming techniques. Jammers do just what their name suggests — they're intended to disrupt and confuse enemy radar systems. The most complex jammers are electronic in nature.

Electronic Jammer

Electronic jammers are power-devouring devices that emit high-intensity microwaves. The first jammers merely filled the sky with random radar frequencies, but overheated easily and were not always effective. Modern jammers are carried in several pods partially built into the wings and fuselage. They have several different operating modes, including noise, pulse, continuous wave, transponder and repeater.

Part of the RWR's function is to direct the intensity, frequency and direction of the jamming transmission. When incoming radar is detected by the RWR, the threat is analyzed. The RWR then determines the correct response mode.

Noise mode radiates wide-area emissions that fill the sky with "junk" radar readings. *Pulse* mode emits pulsed transmissions, while *continuous wave* gives off uninterrupted signals. However, the fact that some radar beams are reflected from the aircraft's skin back to the source is the basis for *transponder* and *repeater* modes. Both take over the radar's automatic gain control.

In transponder mode, the jammer alters the radar reflection by sending back a pulse with a small time delay and a larger amplitude than the original. This causes the radar scope to display a larger target, off-course from the aircraft's true position. Repeater mode conveys inaccurate directional and altitude information by sending back inverse reflections. Intense signals are returned as weak ones, and weak ones are amplified into strong returns.