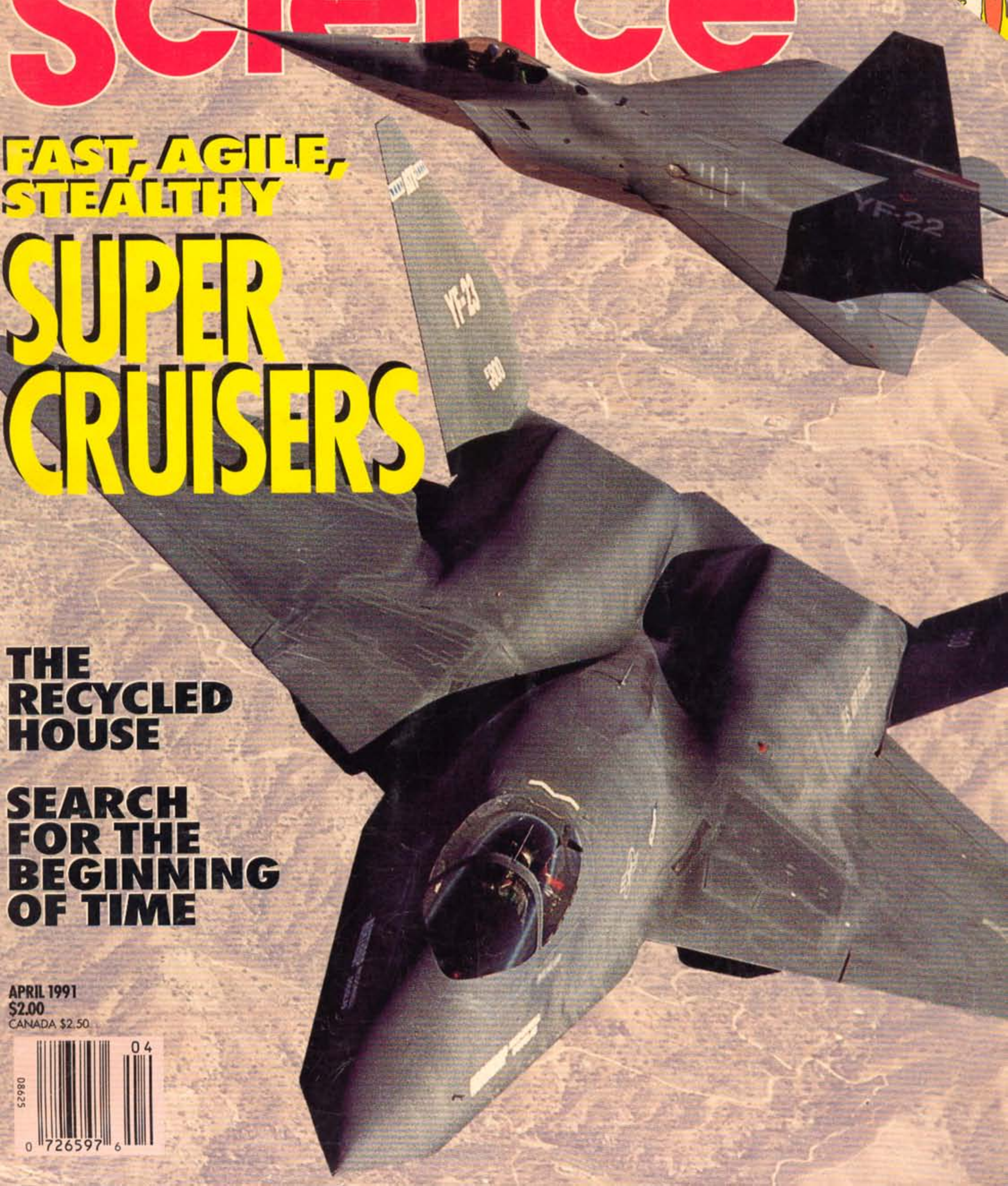
Popular Science

GULF WAR
HIGH TECH HITS AT IRAQ



FAST, AGILE, STEALTHY
SUPER CRUISERS

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Northrop's ominous-looking YF-23 (above) and Lockheed's sporty YF-22 (right) both aspire to be the Air Force's next generation Advanced Tactical Fighter.

FAST, AGILE, STEALTHY

SUPERCRUISERS

By STUART F. BROWN

In the grim business of air-to-air combat, the pilot who first spots his opponent and dispatches a deadly missile is likely to be the one who survives to fly again.

Imagine fighter planes engineered to prevail by launching missiles at foes who have yet to glimpse their attackers—or even be alerted by warning devices to the approaching danger. The Air Force has been dreaming of such aircraft for years, and now is mulling over two pairs of ultra-high-performance prototypes designed with the pugnacious slogan "first look, first shot, first kill" as inspiration.

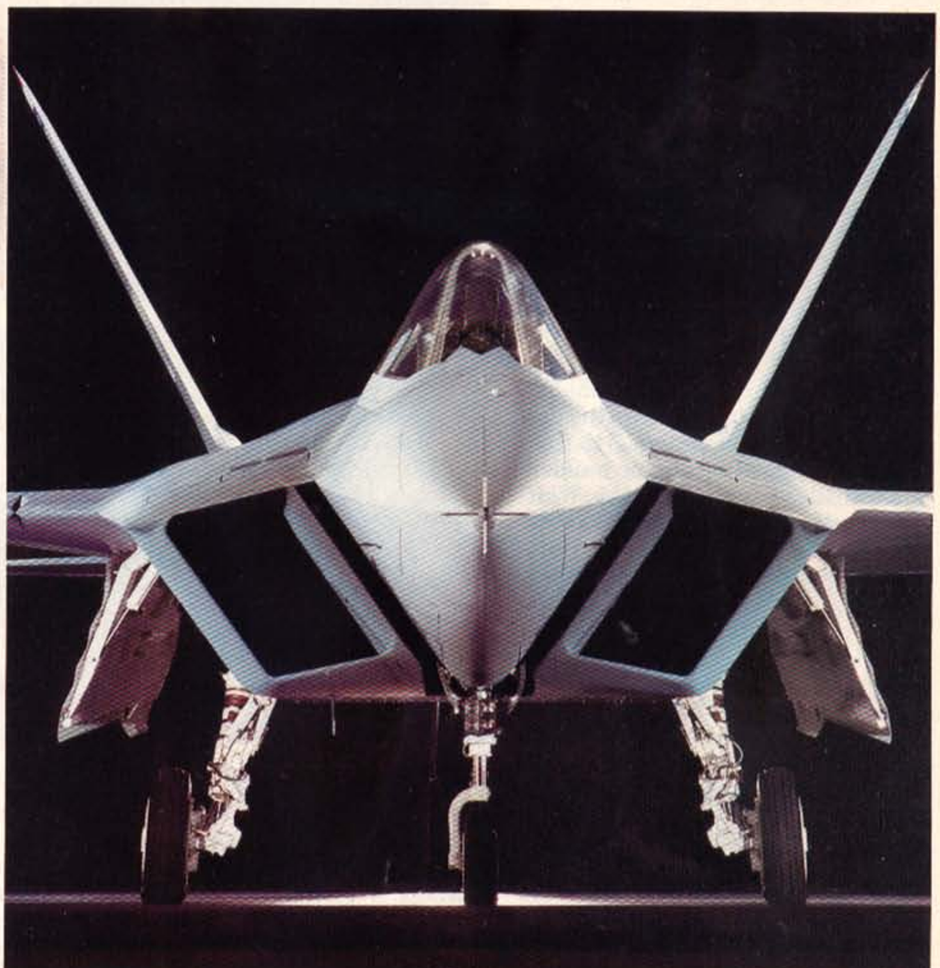
The YF-22s and YF-23s that completed a fast-paced flight test program at Edwards Air Force Base in California last December demonstrated performance never achieved by previous aircraft. Their most startling breakthrough was accelerating to "supercruise" at sustained speeds above Mach 1.5 (about 1,200 mph) without resorting to afterburners that would more than double fuel consumption.

Both airplanes showed great agility and are claimed by their builders to possess substantial stealth characteristics that make them difficult to detect with radar, infrared, and other sensors—the key to bushwhacking an unsuspecting adversary while minimizing vulnerability to surface-to-air missiles. One of the twin-engined fighters even uses movable exhaust nozzles that can vector thrust up or down for increased pitch control.

The Lockheed/General Dynamics/Boeing YF-22 and Northrop/McDonnell Douglas YF-23 are the competing entries in the Advanced Tactical Fighter (ATF) program the Air Force established several years ago ["21st Century Superfighters," Oct. '86] to develop a successor to its current air superiority fighter, the F-15, which entered service in 1975. At the end of this month, the Air Force is due to announce the winner of a heated race that has seen the five big aircraft companies invest about $1.4 billion of their own money for a crack at what may be the last big fighter purchase for a long time.

The program's total cost (which could reach $100 billion or more for 750 aircraft, with the possibility of further spending for a Navy version to replace the F-14 fighter) has the aerospace industry salivating in an era of declining weapons spending. It also

Two pairs of hot prototype fighters have been showing their stuff high above the California desert. Next month, the Air Force will pick one to replace the F-15.



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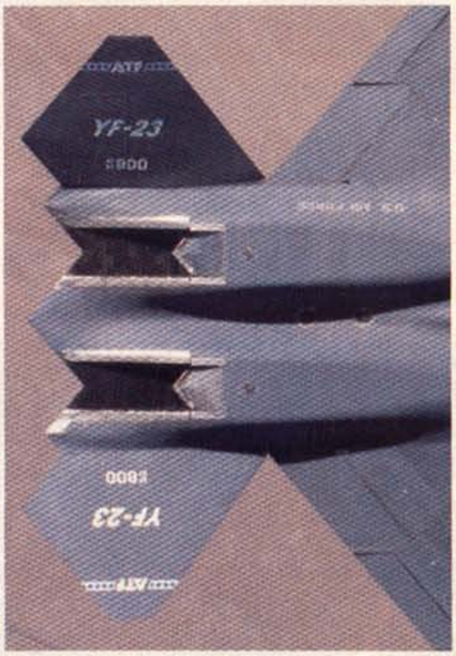
The extreme outward cant of the Northrop YF-23's big twin tails (left) helps confound enemy radars and gives the pilot an excellent view over his shoulder. A look from above (below, left) shows long troughs aft of the engines designed to minimize the fighter's infrared signature by mixing hot exhaust with cooler air. The Lockheed YF-22's protruding thrust-vectoring exhaust nozzles (below, right) present a tougher cooling challenge. During flight tests, the Lockheed airplane (bottom) launched a Sidewinder missile from an internal weapons bay.



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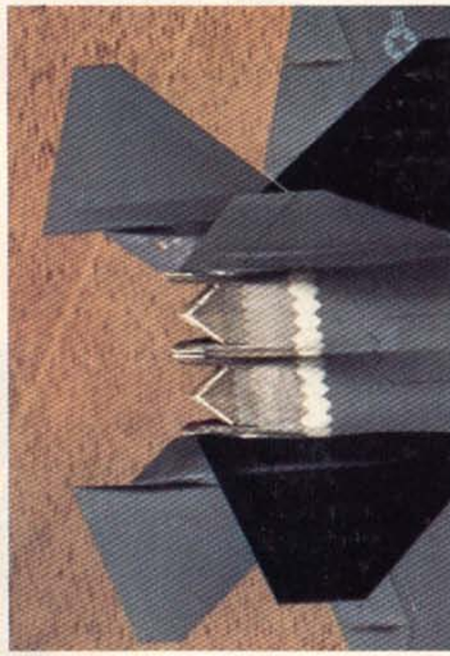

LOCKHEED CORP.

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has inspired a number of critics in Congress and elsewhere to question the need for the ATF, which was conceived to battle swarms of Soviet fighters in the skies over Central Europe, a scenario that now seems unlikely (see box, Do We Really Need the ATF?).

Rationale and cost aside, the prototypes are fascinating machines that embody significant advances in high-performance airframe, engine, and avionics technology. They also reflect the individual philosophies of design teams that arrived at two quite different responses to the purposely open-ended "wish list" of performance requirements issued by the Air Force. If funding continues, the winning team will proceed to a full-scale development program involving design, manufacture, and flight testing of an initial batch of 11 production-version ATFs. The losing team will go away empty-handed.

Plenty of thrust is what enables the YF airplanes ("Y" is the designation for prototypes) to travel so fast. Competing engine builders General Electric and Pratt & Whitney developed advanced turbine designs for the ATF program that produce 35,000 pounds of thrust apiece, yet weigh about the same as the 25,000-pound thrust engines used in the F-15.

One of Lockheed's YF-22s is powered by two GE engines, the other by Pratt & Whitney's; Northrop's YF-23s are similarly equipped. This is so the Air Force can identify the most successful of the four combinations of power plants and airframes. General Electric's YF120 engine uses a variable-cycle design (see box, Mach 1.6 With Decent MPG), which improves its efficiency at slow-to-medium speeds, while Pratt & Whitney's engine sticks to a simpler arrangement.

Although the ATFs can save fuel and gain range by supercruising, their engines are still equipped with afterburners, which increase power 50 percent above full-throttle output. Fighter pilots insist on having this reserve for moments when a burst of scorching acceleration may be the only way to catch or elude an agile opponent.

A second element contributes to the ATFs' speed: reduced drag. By storing fuel, missiles, and a cannon inside the aircraft, designers were able to keep the exterior shape aerodynamically clean—and free of radar-reflecting appendages—compared with fighters that carry these items under their wings. But cramming so much underneath the skin also caused the ATF prototypes to grow somewhat larger than the F-15, particularly in wing area. They may also be heavier.

The plethora of classified features

on the airplanes makes it hard to assess objectively their relative performance. However, some observers think the Northrop design places more emphasis on stealthiness, while Lockheed's approach somewhat favors agility. There are several reasons for this.

Viewed from above (see diagram on page 66), the leading and trailing edges of the tails, exhaust area, and clipped-diamond wings of Northrop's YF-23 are parallel to each other, limiting the number of directions to four in which radar could reflect from these surfaces. Presumably, radar-absorbing materials are used on the edge areas to reduce the likelihood of distinct radar beams, or lobes, returning to their sources.

The YF-23's serrated tail silhouette and its engine-exhaust outlets sunk into deep troughs are reminiscent of another Northrop product, the B-2 stealth bomber. Interestingly, the YF-23's nose, with its pinched chines, or ridges, blending back into the main wing, calls to mind an early example of a radar-foiling design, rival Lockheed's SR-71 Blackbird spy plane. The YF-23's steeply canted twin tails are conceived to reflect radar beams in a direction where they will likely remain undetected.

By comparison, the F-15's tall, upright tails look like a pair of barn doors. Such a shape is now unthinkable for a fighter, which seeks to avoid reflecting radar sideways at the fairly shallow angles believed to be most likely to betray its presence.

Lockheed's YF-22 is a more conventional-looking craft, with traditional pairs of horizontal and vertical tail surfaces. A topside view reveals leading and trailing edges running along more angles than do the Northrop plane's, increasing the number of reflected radar lobes.

Burying engines deep within the fuselage has become a classic trick in "low-observable" aircraft design, and the two YFs are no exception. Radar-absorbing serpentine "S" ducts shield the metal fan sections of the turbines from prying microwaves. The importance accorded to keeping engine parts shielded from sensors is particularly evident in the widely spaced trapezoidal air inlets under the Northrop YF-23's wings and the fat engine bulges atop its aft fuselage. The arrangement of the YF-22's engines and intakes is more subtly submerged into its overall shape.

Either YF can earn top scores on the "looks fast standing still" index familiar to airplane buffs, depending on

DO WE REALLY NEED THE ATF?

JOE CUPIDO/AIR PHOTO

Soviet Sukhoi 27 fighters are said to be formidable machines, in some ways equal to the F-15.

The Air Force claims the Advanced Tactical Fighter (ATF) is required to counter front-line fighters such as the Soviet Mig 29, Sukhoi 27, and their eventual successors. Western coalition fighters have recently engaged in combat with Iraqi-piloted Mig 29s sold to Iraq by the Soviets. Critics argue that improved versions of current U.S. aircraft, such as the proposed F-15XX and F-16, Falcon 21 will suffice.

Last May, a small group of American specialists were taken on a tour of Soviet aircraft development centers. One of those attending was Dr. Charles W. Kauffman, associate professor of aerospace engineering at the University of Michigan. "We didn't see anything like an ATF, although we didn't look in every corner," he reports.

Following are the views of military aircraft experts contacted by POPULAR SCIENCE.—*S. F. B.*

"Clearly, we're going to need to replace the current generation of fighters at some point. The question is with what and how soon? Air Force missions against Iraq or North Korea don't demand the same level of technology as the Soviet threat that was anticipated. With the end of the cold war, the Soviets are not modernizing to the extent we thought.

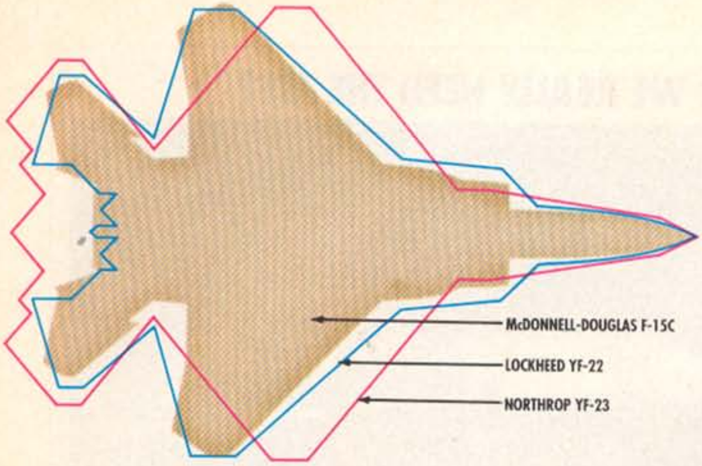
"We can bridge the gap between an ATF and our current fighters by upgrading some of the existing aircraft. When we eventually do develop a new-generation ATF, perhaps around the year 2010, it need not be quite so fancy a system as the one the Air Force is working on. An old adage in weapons acquisition is that the last five percent of capability is fifty percent of the cost."—*Alexis Cain, research director, Defense Budget Project, an independent research organization that provides public information on defense spending and policy issues*

"Even though the prospect of a U.S.-Soviet confrontation in Central Europe has become implausible enough to be almost pure science fiction by now, there are high-quality Soviet-made aircraft in air forces around the world that are not friendly to us. Having flown the Mig 29 and every fighter in the U.S. Air Force inventory, I know that the Soviet fighters are formidable adversaries.

"I think we should have an ATF. For the near term, we could probably get by with doing nothing. But we've eventually got to modernize the force by replacing the F-15. If I were in charge of setting requirements, I would have liked to come up with an airplane a little bit less exotic than these two prototypes that cost less and would do somewhat fewer things, while still keeping us in the game at the leading edge. No country can afford a $100 million fighter."—*Benjamin S. Lambeth, senior research staff member, International Policy Department, Rand, a contract think tank*

"The ATF was designed not to perform a clear mission, but to carry a laundry list of technologies: stealth features, radars, flight controls, internal weapons, et cetera. And the Air Force wasn't willing to accept any cheap technologies. This is exactly the opposite of the way you go about trying to make an affordable airplane that works.

"If air-to-air fighting were the ATF's real mission, it could be built as a small, superbly maneuverable aircraft with an extremely high thrust-to-weight single engine and not an extra ounce of weight. This would allow it to supercruise at Mach 1.2 to Mach 1.5 for half an hour. The two ATF prototypes grew so heavy they lost the ability to supercruise long enough to be likely to surprise an enemy from behind. Speed leads to surprise, and so does simply being small; it makes an airplane hard to see. Designers have been trying to achieve beyond-visual-range killing of enemy fighters since 1958, but, at most, four such kills have been accomplished. The reason is simple: There is still no reliable sensor that can tell friends from foes."—*Pierre Sprey, a defense consultant and former Pentagon official who worked on developing the A-10 and F-16 aircraft and the supercruising fighter concept*



Superimposed plan views of the ATF prototypes and a McDonnell Douglas F-15C reveal similar lengths, while the new aircraft have considerably greater wing area. Stealth considerations make the F-15's boxy engine air inlets obsolete. The ATFs breathe through smoothly contoured openings.

the mood of the moment. Such democratic sentiments are scarcer among members of the industrial teams that built the planes, though; each camp tends to feel its contender is clearly the beautiful one. The stress of competition has even caused combative thoughts to creep into some minds: A tiny YF-22 was recently observed pursuing a tiny YF-23 across one Lockheed manager's lapel.

Lockheed's designers chose to equip their prototype with a wild feature: two-dimensional thrust vectoring. It consists of a movable heat-resistant metal nozzle (possibly coated with ceramic) that directs engine exhaust up or down to improve maneuverability at certain speeds.

A computerized flight-control system blends the vectoring commands with those directing the aircraft's flaps, tails, and other normal control surfaces, so the vectoring operation remains "transparent" to the pilot.

"I don't feel anything kicking in," says Lockheed chief test pilot Dave Ferguson. "I just get double the roll rate at low speed. The vectoring controls pitch, while the differential tails input roll at a stronger rate than they could otherwise, so I can turn about twice as fast. Above Mach 1.4, when the tail loses some of its effectiveness, vectoring lets me turn about one-third faster. We think the added weight and complexity of the system have more than paid their way."

Robert R. Sandusky Jr., chief designer of Northrop's YF-23, carefully considered the idea of using thrust vectoring—then rejected it. "We didn't see a payoff. Wings should lift and engines should push, and they don't do each other's job too well," he says adamantly. "Engines just aren't the efficient way to make lift."

Northrop's curvaceous yet somewhat sinister-looking number-one prototype rests in a highly secured hangar at Edwards Air Force Base. A walk around the big black-skinned warbird with chief test pilot Paul Metz allows a peek at the formerly classified area between the big tails. Here, instead of thrust-vectoring hardware, one sees the effort engineers invested in minimizing the infrared signature generated by the fighter's exhaust heat—particularly when viewed from below.

The twin turbines' 2,300-degree-F exhaust gases run through deep troughs lined with tiles made from temperature-tolerant titanium aluminide intermetallic material. Lamilloy cooling technology developed by General Motors' Allison Gas Turbine division is used to extract vast amounts of heat from the tiles by pumping air through a maze of tiny internal passages and surface holes. This keeps the temperature of the composite underside of the tail several inches below at only 300 degrees F, according to Thomas R. Rooney, Northrop's vice president and ATF program manager.

When the Lockheed YF-22s take off, a fiery glow is visible in their short exhaust nozzles. Some engineers speculate that the thrust-vectoring design could emit a stronger infrared plume than does Northrop's recessed nozzle design, but this may also be countered by infrared-spoofing equipment on the aircraft.

About 15 years ago, when stealth technology was hidden from view in highly classified "black" research programs, reducing observables seemed to be drastically at odds with the aeronautical design principles known to make aircraft well-behaved in flight. Recent advances have prompted aeronautical engineers to toss this notion out the window.

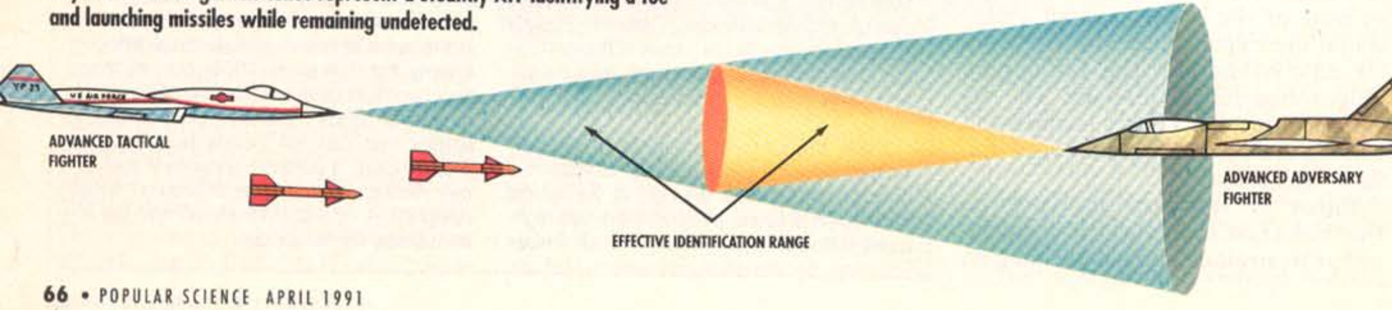
"You may not believe this," is the way Lockheed ATF-program general manager Sherman N. Mullin prefaces a startling claim. "It isn't a case of stealth or agility anymore. You can have both. The reason it took us a year longer than we originally thought to get the external shape of our airplane nailed down was because we set the goal of having low-observable characteristics in the same league as the F-117 stealth fighter, with better maneuverability than any current fighter. And that's what we've got."

Northrop officials echo this opinion. "What's good from an observables standpoint turns out not to be so bad aerodynamically," says ATF manager Rooney.

Continuing experimentation has yielded a family of techniques that includes subtly refining the shapes of components such as exhaust nozzles and air inlets to achieve both goals at once, says Mullin. "We didn't know how to do this five or six years ago, and we sure didn't know how when we designed the [notoriously graceless] F-117," he says with a chuckle, "even though that's a slick-looking airplane aerodynamically, you've got to admit."

Does supercruising feel as sporty as it sounds? Lockheed's Ferguson says his airplane simply accelerates smoothly away from the F-15 chase planes used during flight testing. "There's no way they can stay with the prototype. I was burning about two-thirds as much fuel as the afterburn-

The combat doctrine underlying the ATF effort stresses surprise attack from beyond visual range. The cones represent a stealthy ATF identifying a foe and launching missiles while remaining undetected.



ing F-15 that was chasing me at a slightly lower Mach number."

During flight demonstrations, the Lockheed airplane equipped with General Electric engines supercruised at Mach 1.58 at 40,000 feet. Northrop's GE-powered version exceeded Mach 1.6 in supercruise, while its Pratt & Whitney-powered twin reached a speed of Mach 1.43.

With afterburners lit, a Northrop plane reached Mach 1.8 at 50,000 feet, while one of Lockheed's hit a classified speed "in excess of Mach 2.0." The flight program showed that the Pratt & Whitney engines produced less thrust, although further-developed versions of both engines will be tested before the Air Force chooses one to power the production ATF.

Rapid progress is occurring in another key field: making aerospace structures from lightweight composite materials. The YF prototypes are built from about one-third plastic materials; production ATFs would contain more. A new generation of toughened polyimide resins with the tongue-twisting appellation bismaleimides (BMI is easier to say) is being used in graphite composites, with two to three times the high-temperature toughness of the epoxy resins available in 1985.

New thermoplastics are even tougher, but less tolerant of high temperatures, so they are being used to make damage-resistant landing-gear doors and access covers used on the relatively cool undersides of aircraft.

Northrop's YF prototype was built from the outside in—which is the opposite of the customary procedure for fabricating aircraft. "Boats are built this way because they've got to come out of the mold with a smooth outside surface," explains Martin J. McLaughlin, Northrop's manager of manufacturing technology on the YF-23 program. "Surface smoothness and shape blending are very important for low-observables reasons, so now we're doing the same thing with airplanes."

At Northrop's integrated composites center in El Segundo, Calif., where the YF-23's plastic parts were fabricated, McLaughlin likes to show off a huge 11-by-17-foot graphite-composite part that would be used on a production ATF to replace five individual skin sections used on the prototypes. The single, deeply contoured part has integral stiffeners and longerons inside its skin and forms a large area of the distinctive double-humped surface covering the YF-23's engine bay. He urges visitors to gaze down the as-molded surface looking for wavy reflections, indicating surface imperfections. There aren't any.

A comparable metal assembly would contain buckets of fasteners connecting scores of parts and require extensive hand-finishing to even approach the surface smoothness of the composite part. It would also weigh more.

The ATF prototypes use computerized flight-control systems that make subtle corrections to the various control surfaces at a rate no pilot could hope to match. Rather, the pilot indicates with the throttles and control stick where he wants his aircraft to go, and it figures out the best way to do it. Such a system requires ultra-quick computers and control actuators governed by reams of software containing control solutions for every conceivable condition that could occur in flight.

Flight-control software for the YF-22 was written by a team of 50 specialists working for 30 months at General Dynamics' Fort Worth, Texas, facility. The first version intentionally lacked thrust-vectoring commands to keep the early stages of flight testing simple. Two subsequent versions incorporating vectoring commands and other refinements were loaded into the YF-22 computers as the program advanced.

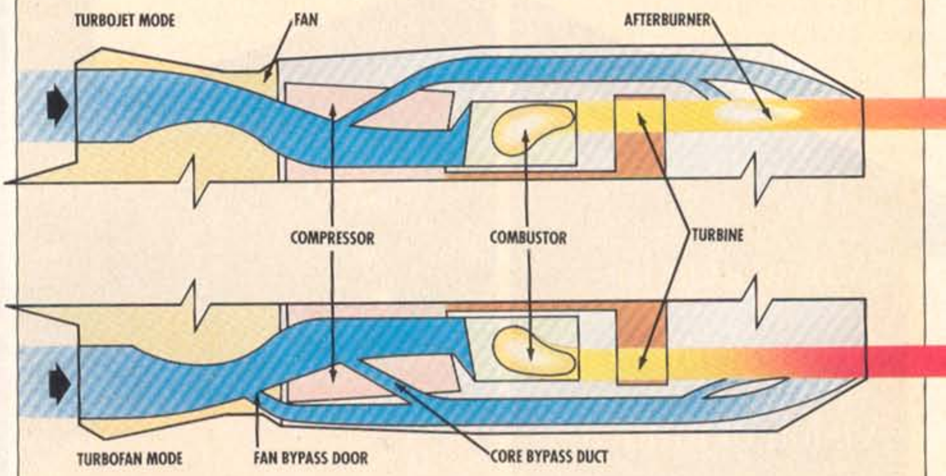
How do software engineers know what to tell a fighter plane's control computers? They get their cues from experienced fighter pilots who put in countless hours "flying" ATF missions on powerful simulators. "The simulator flying has paid off for us because we have not encountered any major surprises in testing," says Lockheed's Mullin.

Spectators at the first flight of Northrop's prototype noticed its huge all-moving tails—each larger than a small fighter's wing—quivering like butterfly wings as the airplane taxied out to the runway. Test pilot Metz says this occurred because the early generation flight-control software didn't include instructions to ignore motions in the airframe caused by pavement bumps. The answer, he adds, is inserting lines of computer code that tell the system not to try to correct for conditions sensed when the fighter's full weight is on its nose landing gear.

An essential element of the ATF pro-

[Continued on page 94]

MACH 1.6 WITH DECENT MPG



The source of the Advanced Tactical Fighter's (ATF) remarkable and efficient supercruising ability—and the extended flying range it confers—is a pair of advanced-design jet engines that produce 10 pounds of thrust for every pound they weigh, a 25 percent improvement over the latest F-15 and F-16 engines.

Engine-building rivals General Electric and Pratt & Whitney each developed ATF power plants using fewer and lighter-weight internal parts made from exotic materials tolerant of increased operating temperatures that extract more of the energy contained in kerosene jet fuel ["21st Century Hot Jet Engines," June '90].

As a rule, a turbine engine is most efficient when the velocity of its exhaust gases equals the speed of the aircraft it propels. GE's YF120 variable-cycle engine (above) has the ability to adjust its operation for the best fuel efficiency at varying speeds. During takeoff and subsonic cruising, it operates as a turbofan, pumping large volumes of hot gas and bypass air at a moderate velocity. During supersonic flight at high altitudes, movable fan-bypass doors direct more of the airflow through the engine's core, transforming it into a turbojet that generates a high-velocity exhaust stream. The YF120's bypass doors are reported to be activated by aerodynamic pressure and to add only 10 pounds to engine weight.

Pratt & Whitney, which built the still-secret variable-cycle J58 engines used in the ultra-fast SR-71 Blackbird spy plane, opted for a less complex design for its YF119 ATF engine.—*S. F. B.*

DRAWINGS BY MARIO FERRO

Supercruisers

[*Continued from page 67*]

gram has been developing a next-generation avionics package consisting of arrays of sensors, navigation and communications systems, and enemy-bamboozling electronic countermeasures gadgets that are tied together by monster chips with almost supercomputer processing speeds. This torrent of data can be reduced to colored symbols displayed to the pilot on bright flat-panel cockpit screens designed to keep workload and confusion to a minimum.

"Sensor fusion" and "situation awareness" are the buzzwords of the ATF avionics effort. The philosophy behind this cockpit design is letting the pilots select the type of information they want from the displays at a given moment, according to Mike Major, manager of ATF operational requirements at Northrop. "The pilot can choose to see information ranging from raw radar blips all the way up to fully fused information—the sky and ground around him presented in an intuitive format that uses colors and symbols. It's an icon world," he explains.

Normally, the displays won't burden the pilot with readings such as engine temperature or hydraulic pressure. "We don't provide that information unless he asks for it or something actually goes wrong with one of these systems. We're freeing him from trying to integrate all this data so he can project events several seconds into the future and determine: Am I offensive or defensive right now?" Major says. "If he wants, the pilot can choose to see an iconic presentation of the sky ahead of him or look down from the 'God's eye' perspective in which his aircraft occupies the center of a display that identifies friends, foes, and threats on the ground from all directions."

Lobbying for funds

The media-shy Air Force general in charge of the ATF effort chooses to promote and defend his program largely behind the scenes in Washington, D.C., while assertive salesmanship comes easily to Lockheed's Mullin. "I think stealth gives us a permanent change in air superiority, the biggest since we went from propellers to jet engines. It gives us major advantages relative to ground missiles and adversary aircraft," he proclaims. "Combining stealth with supercruise, we get capabilities that just aren't in the cards for derivatives of F-15s or F-16s. Do we want to invest in a fighter that will be superior to the threats—whatever the hell they are—in the twenty-first century? It's a fundamental national defense issue." PS