Radar's Growing Vulnerability

As weapons become smarter, they learn to "see" radar beams as pathways to their target, gaining an advantage over defensive systems

AFTER serving for four decades as the primary shield against attack from the air, radar is losing its defensive power. With the advent of radar-seeking missiles and the military equivalent of the "Fuzzbuster," the combatant who relies heavily on radar will be in peril.

The sinking of the British destroyer HMS *Sheffield* by an Exocet missile during the Falkland War was a striking demonstration of how smart weapons have changed the rules of modern warfare. An Argentine fighter flying 20 miles away was able to destroy a $50-million warship with a single shot. Under slightly altered circumstances the target might have been one of two British aircraft carriers—a blow that could have reversed the course of the war.

It has always been difficult to locate enemy ships at sea. Yet the Argentine fighter found the *Sheffield* while flying at the very limit of its fuel range because the ship, like those in the U.S. Navy, was operating with its radars on to guard against incoming enemy fighters. Rather than protecting the ship, the radar acted as a powerful beacon that gave away its location.

In the not-too-distant future, says Robert Cooper, the former head of the Defense Advanced Research Projects Agency, "the game will become hiding and finding." As the accuracy and range of smart weapons grow ever greater—to the point where even a single shot of a guided projectile may be able to kill a tank, plane, or ship—finding the target may be tantamount to destroying it.

An enemy equipped with a Fuzzbuster may be able to quickly determine not only the location but also the size and identity of any approaching force. As the highway battle between police and speeders has aptly demonstrated, the listener starts with an advantage.

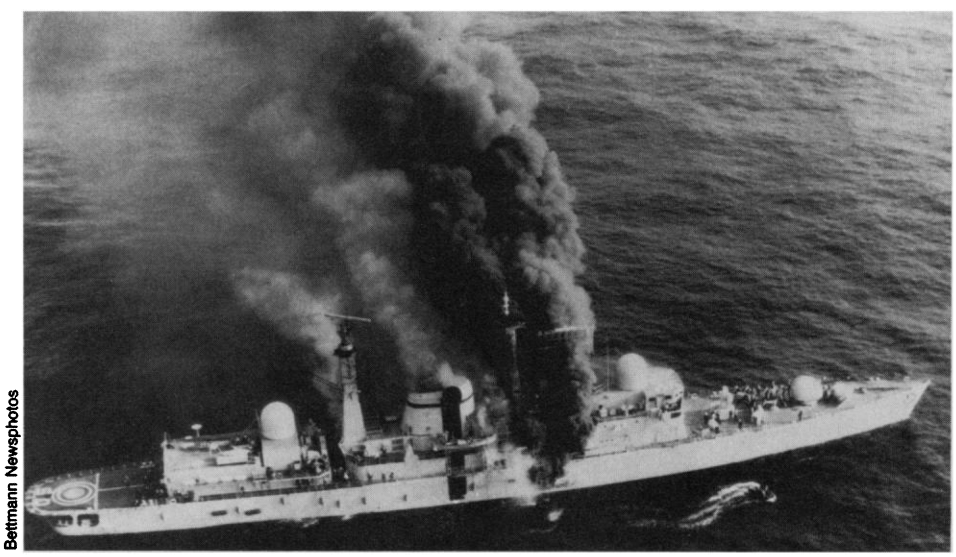
A radar emits a signal whose power drops off with the square of the distance it travels—the inverse square law. That's the signal the Fuzzbuster is trying to detect. But the radar operator has a much more difficult task. He has to pick up the reflected echo signal coming off the target. That signal has been reduced by a further factor of the distance squared, since the already weakened signal striking the target is scattered in all directions. Thus the radar operator is listening for an echo that drops off with the fourth power of its distance to the target; the signal that the Fuzzbuster-equipped listener is trying to detect has dropped off only with the second power. That asymmetry colors much of the debate over efforts to disguise radar signals.

Even as some of the Pentagon's own planners have begun to warn of the growing vulnerability of radar-equipped weapons, American tactical warfighting plans still largely take for granted the unrestricted use of radar. Radar carried by the $1-billion apiece Aegis guided-missile cruisers is the cornerstone of the Navy's plans for defending vulnerable aircraft carrier groups against air attack. The entire design of Air Force fighters is predicated on the unfettered use of on-board radars to locate targets and direct missiles. The aircrafts' expensive fire-control systems, the missiles they carry, and even their size and weight are determined by their radar systems. The large radar carried on the top-of-the-line U.S. F-15 fighter, for example, weighs in at 10,000 pounds, if the associated generators and air conditioners are added in, or about one-fifth of the total weight of the plane. The new advanced medium-range air-to-air missiles (AMRAAM) —which cost half a million dollars apiece— are guided to their target by the aircraft's radar system. Bombers designed to penetrate enemy territory—the older B-52s and F-111s, plus the B-1Bs and F-15Es now being acquired—depend on terrain-following radar to guide them at low altitudes through hostile zones.

Air Force tactical plans likewise are designed around the use of the large AWACS radar surveillance planes to direct U.S. interceptors. A similar 707-sized radar plane, called JSTARS, designed to follow the movement of ground forces, is the centerpiece of U.S. Army and Air Force plans to carry the battle behind enemy lines.

But, as Pentagon tactical warfare chief Donald Fredericksen recently noted, on the battlefield of the future, if you radiate you may be dead. As if to underscore that point, the Soviet Union recently deployed a new air-to-air missile, the AA-10, which is believed to have the ability to home in directly on radar emissions from target aircraft.

In addition, the Soviets have taken some crucial steps to free themselves from a dependence on radar. For 20 years they have put a strong emphasis on optical guidance systems. The SA-6 and other Soviet antiair-



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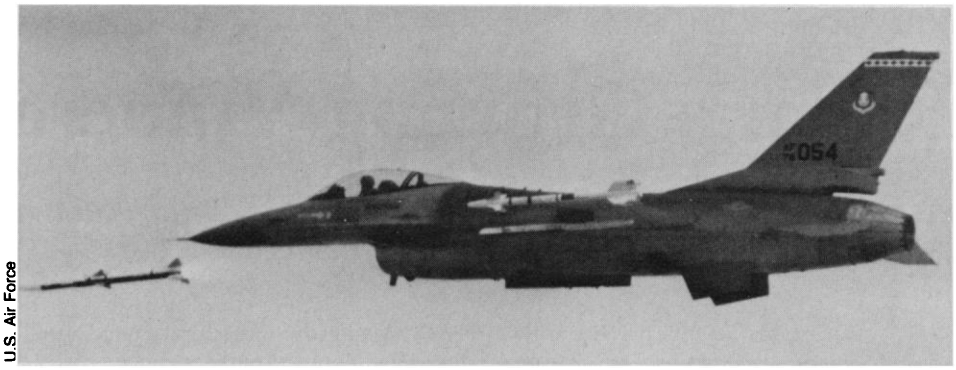
HMS *Sheffield* *was hit in the Falkland Islands war in 1982 when its radars attracted a rocket launched from a fighter plane 20 miles away.*

craft missiles have both radar and optical tracking modes. In the optical mode the gunner keeps the target lined up in the cross hairs of a sight while a TV camera system on the ground automatically tracks a flare carried on the missile's tail. The tracking computer measures the angle between the two and sends steering corrections to the missile over a radio link. An SA-6 battery deployed by the Syrians in Lebanon shot down an Israeli F-4 fighter in 1982. The similar French-built Roland missile was used by the Argentine forces in the Falkland War to down five, and possibly six, British aircraft with eight shots, according to the manufacturer. At least one of those kills was achieved in the optical mode.



AMRAAM antiaircraft missile, *a new $500,000 item, uses radar guidance and may be vulnerable to radar-targeting or jamming.*

Recent advances in passive sensor technology—especially improved infrared (IR) sensors, which can detect targets without giving off any radiation themselves—have pushed the debate between radar critics and radar enthusiasts to the fore. Critics say that the time has come to move away from a dependence on radar. Rather than use large radars in fighter aircraft to sweep the skies in search of enemy planes, infrared sensors could pick up the targets and determine their angle; a much smaller radar could be turned on in a "short squirt" at the last second to measure the target's range just before firing a missile. Interestingly, highway police have begun to adopt a similar tactic to counter Fuzzbuster-equipped speeders. Rather than trolling continuously with their radars, and thus alerting speeders of their presence, they are now beginning to use radar only to stop a speeder they've already picked up by visual observation. "Obviously, the highway police are a lot smarter than the people who design fighter planes," says one former aircraft designer.

Instead of using expensive and vulnerable active-radar missiles, fighters could be equipped with IR-guided weapons (such as the Sidewinder missile) plus air-to-air antiradiation missiles. Once U.S. forces are equipped with passive sensors and antiradiation missiles, it is argued, the radar game would become irrelevant. Efforts to overcome enemy radars with clever countermeasures such as jammers and radar-invisible "stealth" designs would simply be a wasted effort: an enemy who turns on his radar or jammers would become a sitting duck.

Radar enthusiasts on the other hand are pressing ahead with a variety of technical fixes to make radars less detectable to an enemy. So far, this approach has controlled policy. Enormous sums have been invested in radar in U.S. forces. JSTARS is to cost $4 billion; much larger sums have been spent to acquire the 34 AWACS planes and the radars installed in every fighter and bomber. An unknown amount is going into "black" programs to develop a variety of advanced airborne reconnaissance radars designed to elude detection.

Some protective half-measures have been taken that indicate an awareness of radar's vulnerability. "Threat warning receivers" that can detect Soviet radars and measure their bearing are being acquired for U.S. fighters. The Air Force and Navy have deployed several air-to-ground antiradiation missiles designed to attack Soviet surface-to-air missile sites. The latest, now in the final testing stages, is a jet-powered drone called Tacit Rainbow. It is designed to penetrate enemy territory, circle until a SAM antiaircraft radar is activated, and then dive in for the kill.

The threat of Soviet antiradiation missiles is given as a justification for the development of small radar-transmitter decoys that can be towed behind an aircraft or ejected. The Navy has begun to equip its F-14 fighters with focal-plane-array IR sensors. They contain 16,000 separate elements on a single chip and provide dramatically improved resolution over previous, mechanically scanned IR systems. In tests, the devices have detected aircraft at 100 kilometers and identified small commercial planes by type at 15 kilometers.

On the other hand, the Pentagon makes clear that it views the IR devices as "complementary" to radar, not a replacement. Other steps taken by the Pentagon show that it is still firmly committed to playing the radar game. The Air Force and Navy have yet to show any interest in developing an air-to-air antiradiation missile. A program to develop such a missile was killed in the 1970s. Meanwhile, the Air Force and Navy are spending billions on radar jammers. For example, a $300-million program is under way to upgrade the jammers carried on 36 F-111 bombers that have been modified to perform a full-time electronic warfare role. Current plans also call for equipping all current advanced fighters with new "Airborne Self-Protection Jammers," at a cost of more than $5.5 billion.

The most expensive commitment to the belief in the continuing role of radar is the attempt to develop the stealth bomber, designed to reflect a smaller radar signal. But even a low-observable airframe such as this could be vulnerable if it emits radar signals from its own equipment.

This vulnerability has led critics to question the investment in large radar platforms, AWACS and JSTARS in particular, arguing that they would be sitting ducks in wartime. The Air Force responds that it can protect these aircraft by keeping them well behind the front line and by providing them with fighter cover. But critics note that Soviet air-to-air antiradiation missiles and the long-range, supersonic surface-to-air missiles such as the SA-12 would nullify even those measures.

The game of making radar signals less noticeable can become a never-ending spiral of clever technologies designed to outwit a previous clever technology. In the literature on radar one finds the term "electronic counter-countermeasures" used unselfconsciously. One approach to resisting jamming is the use of monopulse Doppler radar. Unlike conventional radar, which determines the bearing of a target by sending out a continuous series of pulses as the antenna is scanned across the sky, monopulse radar locates the target's angle by comparing the returning signal at two slightly different points on a fixed antenna. Normal deception jammers attempt to fool a pulse radar by detecting the incoming radar pulse and then transmitting an exact copy of the signal, slightly delayed. Since radars determine range by the time it takes the signal to return, a delayed signal shows up as a second target farther away. But using such a jammer on a monopulse radar would actually give away one's location because the monopulse system calculates by means of triangulation as well as by timing signals.

A recent Soviet book, *Monopulse Radar*

(available in English translation from Artech House, Norwood, Massachusetts), however, describes a number of techniques for jamming monopulse systems, including frequency modulation of the jamming signal. Other U.S. technologies to resist jamming or detection come under the category known generally as "low probability of intercept." They include the use of "low sidelobe" or narrow-beam antennas and spread-spectrum or frequency-hopping transmission.

All of these countermeasures and counter-countermeasures are expensive. For example, the Air Force canceled a proposed upgrade of a jammer pod, known as Seek Ram, when costs escalated to $3 million each—with a total program cost of $2 billion. One of the requirements that drove up the cost was deceptive angle-jamming of monopulse radars.

Some of the counter-countermeasures impose problems of their own as well. One disadvantage of frequency hopping is that it vastly complicates the signal processing requirements for Doppler radar. Doppler radar, which measures the speed of a target by the frequency change of the echoed signal, is especially useful in cluttered environments, such as that presented by a low-flying aircraft when seen from above. So-called look-down shoot-down radars use the Doppler technology; no one has yet developed a frequency-hopping version. The Navy's Aegis system, which is a frequency-hopping radar, does not have a Doppler capability—which means that it can't see sea-skimming targets such as low-flying cruise missiles against the clutter of surface waves.

The most ambitious solution to the problem of radar vulnerability is to put the radar transmitter out of harm's way entirely. At normal radar frequencies, the signal is propagated only along line of sight, limiting the distance that the transmitter can stand off. But at much lower frequencies—around the short-wave broadcast bands—signals can bounce off the ionosphere. Over-the-horizon radar takes advantage of this principle to look thousands of miles away. The United States is now building a network of 12 over-the-horizon Doppler radars around Alaska and the U.S. continental rim as part of the modernization of the strategic early warning system. One general disadvantage, however, is that resolution is poor. Although the system can detect a low-flying bomber or cruise missile from long distances, it cannot determine where the object is within about a 5- or 10-mile block.

Another way to keep the radar off the battlefield is through bistatic operation—placing the radar transmitter and receiver on separate platforms. Loral, which makes the ground-mapping synthetic aperture radar for the highly classified SR-71 spy planes, has reportedly test-flown a bistatic system. The Air Force is also studying the idea of placing radar transmitters on satellites. "In fact the transmitter might even be one of theirs," says one government expert. Although such "noncooperative" illumination is beyond the state of the art for now, it is under study as the ultimate in concealed signals. One difficulty is that the relative locations of the transmitter and receiver have to be known very precisely—to within a wavelength or less.

One interesting feature of this very expensive option is that it may undo another very expensive option, namely, stealth. Stealth designs aim to reduce the reflectance in the direction the beam would be coming from. But "it's basically impossible to make it invisible from all directions," says one expert.

For most military applications, it is unlikely that the near future will see either a markedly reduced reliance on radar or any of these expensive high-tech fixes. Tom Amlie, a long-time Pentagon critic of radar, says that the inevitable result will be a growing vulnerability of U.S. forces. "No sane infantryman would run to the top of a hill, put a flare on his helmet, and dare the enemy to hit him," he says. "Yet radar systems do the electronic equivalent of exactly that." ■

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UC Told to Review Impact of Research

The University of California must set up a review process to ensure that federally funded agricultural research primarily benefits small farmers, the California Superior Court ruled on 17 November. The decision, if upheld, in effect requires the university, which has the largest academic research budget nationwide, to weigh the social costs of innovation to small farmers. The university says it will appeal the decision.

The judgment culminates a lawsuit filed nearly 8 years ago that challenged the legality of spending public research funds to develop labor-saving machinery, including the tomato harvester (*Science*, 30 March 1984, p. 1368). The lawsuit was brought by a group of farm workers and families who own small farms. They assert that mechanization displaces farm workers and drives smaller farmers out of business. The university has argued that the lawsuit threatens academic freedom to pursue research.

Representatives of the farm groups hailed the decision. Debra Jones, executive director of the California Action Network, said in a statement that the ruling "will impact all types of agricultural research, including biotechnology and pesticide development."

But the decision, handed down by Judge Raymond Marsh of Alameda Superior Court, is narrower than it could have been. The ruling applies only to small farms, not farm workers, "who were the original consideration," says William Hoerger, a lawyer for California Rural Legal Assistance, "so that's a disappointment." Ironically, the California Grange, which represents many of the state's small farmers, sided with the university in its defense.

Marsh ruled that the university violated a century-old federal law that says the interests of the family farmers shall be given "primary consideration" by agricultural research projects funded by the federal government. The law, the 1887 Hatch Act, establishes and funds agricultural experiment stations across the country. The university, Marsh stated, "has no process designed to ensure consideration" of small farmers.

Hatch funds account for $4 million or 3% of the university's total agricultural research program, but this money is distributed widely. Hoerger estimates that Hatch funds help support as much as three-quarters of the school's 1400 agricultural projects, so the ruling could have a broad impact.

Marsh ordered the university to submit to the court in 90 days its plans for administrative procedures to weigh the impact of agricultural research projects on small farmers. The university will seek a stay of the order because it plans to appeal, said Christine Helwick, a university attorney.

The problem with the judge's order, Helwick said, is that he "asks us to predict the downstream effect of research and requires that it impacts the right group. It becomes a political guessing game to predict the impact of research and who it is going to hurt."

She said that the university regarded the outcome as "a great victory because the plaintiffs lost or gave up many of the original claims." She noted that the judge did not explicitly say that the university's research was indeed harming small farmers, only that it did not have in place a process to review the effects. But Helwick conceded that if the decision is upheld, it will have a substantial effect on the university's agricultural research. ■ **MARJORIE SUN**