By the turn of the century, fighters may operate around the clock without grounding for electronics failure—and with support requirements consisting mainly of munitions and fuel.

More Sorties—Less Support

BY BRIG. GEN. FRANK S. GOODELL, USAF

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THE Chinese tactician, Sun Tzu Wu, said it in 500 B.C.: "Rapidity is the essence of war. Take advantage of the enemy's unreadiness, make your way by unexpected routes, and attack unguarded spots."

Irrelevant thinking for conventional forces in today's technological era of ICBMs, supersonic fighters, and satellite surveillance? I think not. Through World War II, Korea, and Vietnam, the United States has, in the main, operated from sanctuaries, our bases free from attack and our forces supported by the full might of our industrial strength. Growth in Soviet combat capability has put these sanctuaries at risk. Recent arms-reduction proposals invoke the possibility of greater reliance on conventional forces. And in line with Sun Tzu Wu's thinking, the Soviets are adapting their experiences from World War II and are fielding Operational Maneuver Groups (OMGs) to conduct mobile warfare in the enemy's rear area. Use of the OMGs would be preceded by massive air strikes. At particular risk are the unexpected routes and unguarded spots represented by our basing support system, a crucial element in traditional aircraft sortie production.

The recent Salty Demo exercise highlighted this danger, pitting the USAF Air Order of Battle (AOB) against a simulated Eastern European AOB. The exercise made it clear that significant turbulence at base level can be expected if hostilities begin. It also showed what happens when elements of the air base support complex—facilities, equipment, supplies, and people—are lost or degraded. Specific vulnerabilities include such intermediate-level field operations as liquid oxygen (LOX) facilities and unhardened Avionics Intermediate Shops (AISs). These assets represent the vestiges of planning to operate repeatedly from a safe haven in a conventional environment.

With this developing threat, our air assets and support equipment must be ready to generate sorties rapidly and unfettered by reliance on a vulnerable support structure. To outpunch the enemy, our systems must continuously perform sortie after sortie while reducing to a minimum the need for LOX facilities, AISs, and the like. The way to attain these goals is defined in the Air Force's R&M (Reliability and Maintainability) 2000 initiative. R&M 2000 seeks increased combat capability by acquiring or upgrading systems that perform over time and are easy to maintain. This initiative holds the potential for getting more combat capability while saving scarce people and money.

Operator Calls the Shots

With momentum flowing from the top, the Air Force has geared up for this effort. Foremost in this process are the needs of the operator. The operator, through Statements of Operational Need (SONs), locks in the prime requirement: "Design my system to perform over time and make it easy to maintain." Today, R&M requirements are stated in terms of performance.

The F-15E and Advanced Tactical Fighter (ATF) reflect this new emphasis. A dual-role fighter, the F-15E embodies several significant changes from its predecessor, the F-15C/D. The F-15E will retain its air-superiority features while adding extensive ground-attack capabilities. Achieving the F-15E's full combat capability, as measured by increased sortie rates, requires systems to perform longer, be easier to fix, and have reduced airlift support. As we shall see, a logical, structured approach to technological advances will result in a system that answers the operator's needs.

This new philosophy culminates in the requirements for the Advanced Tactical Fighter. The ATF will be built

—Photo by Paul Kennedy

The Air Force's Reliability and Maintainability 2000 initiative seeks increased combat capability by acquiring or upgrading systems that perform over time and are easy to maintain. As proof that this plan is working, a number of systems no longer have to be brought in and hooked to a bulky Avionics Intermediate Shops (AIS) test set (right), but can be checked and fixed on the flight line. The Line-Replaceable Unit (LRU) that Sgt. Patrick S. Westura and Amn. Ronald E. Lewis are demonstrating in the picture on the left is used for this.

with twice the reliability and half the maintenance (two R/one-half M) of the system—the F-15C/D—it replaces. In performance terms, doubling F-15C/D reliability means the ATF must fly ten consecutive combat sorties before unscheduled maintenance. If grounded, half of the aircraft should be fixed and ready to fly in two hours, using fewer than half the maintainers demanded by present fighters. Supporting airlift for a squadron should be slashed by more than half, to only eight C-141Bs. And this reduced airlift must be sufficient for that ATF squadron to sustain wartime-sortie-rate operations for thirty days at a Third World operating base or austere operating site without additional support.

Based on Air Force Systems Command (AFSC) Project Forecast II projections, the operator of the next century might require systems that operate around the clock for thirty days without experiencing electronics failures that result in grounding of the system. Further, support for these aircraft should consist primarily of vehicles carrying only munitions and fuel.

Requirements that once were no more than a gleam in a war planner's eye now have the solid ring of possibility, if not probability. Technology has already begun to move us away from excessive dependence on vulnerable support assets.

In September 1984, the Secretary and Chief of Staff of the Air Force made R&M coequal with cost, schedule, and performance in systems acquisition. This bold stroke, coupled with such advances as VHSIC, fiber optics, and high-temperature thermoplastics, sets the stage for unshackling combat capability from support complexity. Recent source selections for the Advanced Tactical Fighter and the SRAM II acquisitions demonstrate the Air Force's resolve to implement this concept in consonance with developing technologies.

The Message to Industry

Since February 1985, Air Force R&M requirements have been stated in terms of performance over time and the notion of "if it breaks, make it easy to fix." In this regard, the customer to satisfy becomes the weapon system operator. The designer must realize that for the operator, all performance parameters are zero if a system is broken and not easily repaired due to basic design flaws.

Aerospace industry, when asked to do so, has designed systems that perform when called on for as long as needed. In fact, industry has shown it can go beyond the requirements when given the incentive. Examples range from jet engines to electronics.

For example, the analog scan converter in the B-52's forward-looking infrared system had an expected life of 250 hours. Boeing Military Airplane Co. was awarded a fixed-price contract to develop a replacement system with an expected life of 1,500 hours. Boeing identified high-failure-rate parts. It used digital technology in conjunction with proven off-the-shelf components. By proceeding through an iterative approach, which optimized cost and R&M factors, the company designed a winner. Boeing blew by the 1,500-hour requirement and provided a digital scan converter with a warranted life of 4,000 hours, at a cost of thirty-one percent less per unit, and at a savings of $47 million in ten-year support costs. Furthermore, the system was designed to be easier to maintain.

Products that work when called on for as long as needed while meeting the needs of the customer demand a fully integrated approach. We are seeing managerial realignments in industry that cut across vertical departments and integrate product planning, design, manufacturing, assembly, sales, and service into a team that guides product development throughout its life. The days of tossing the ball over the wall are numbered.

Within the Air Force, we have employed the horizontal approach in designing certain aspects of the C-17 transport aircraft. "R&M quality teams" are being used by Douglas Aircraft, with impressive results in areas ranging from hydraulics to control panel electronics. Many advances occurred simply because the horizontal structure of the team brought together individuals from different functional departments.

As we design our future weapon systems, we must also grapple head on with one of the endemic problems of our manufacturing process. In this country, with some exceptions, we have tended to design to engineering tolerances. Progressive companies design to point target values. We have tried to "inspect in" quality at the end of the production line. The more progressive company adopts a total product development view, where at each step of the manufacturing process they reduce to zero deviations from target values. As our own industry embraces this "variability reduction program," production lines of the future will maintain our carefully designed-in R&M.

Finally, incentives and warranties will ensure design for performance over time and integrity of that design in manufacturing. One strategy promotes increased performance levels during design that would then become the warranted levels during production. For example, the Air Force might include a contract incentive clause that encouraged the designer to go beyond minimum essential requirements of 2,000 hours Mean Time Between Maintenance Action (MTBMA) to, say, 3,000 hours. If the contractor accepts the incentive at Critical Design Review (CDR), then the production contract would warrant the 3,000 hours MTBMA.

The warranty program will take the view that any maintenance action counts as a failure. A "fixed-price repairs warranty" forms the cornerstone. Failure to meet warranted minimum performance levels invokes delivery of consignment spares while repairs are made. This avoids loss of combat capability in the meantime. In addition, failure to meet warranted minimum performance levels would trigger no-cost Engineering Change Proposals (ECPs), with retrofits and forward fits to ensure corrections for the entire inventory.

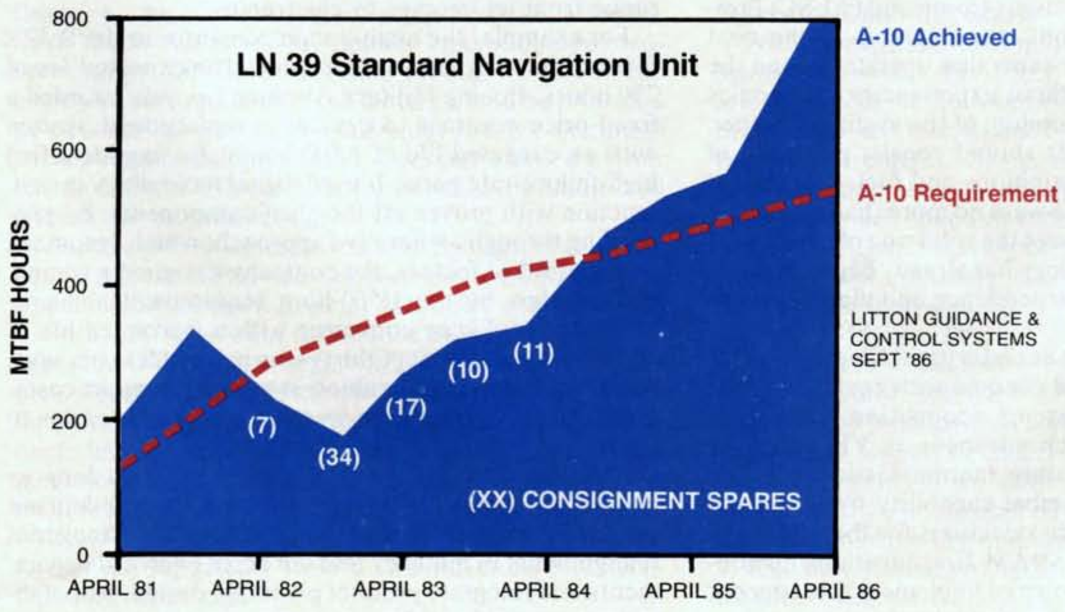
Potentially, everyone wins from these approaches. Because of the fixed price, the greater the actual system reliability, the greater the contractor's profit. The taxpayer gets more national defense for his dollar. The Air Force eliminates Sun Tzu Wu's "unexpected routes and unguarded spots." Excessive reliance on a complex and vulnerable support system will become a thing of the past. Our weapons will stand ready when called on to press the attack as long as needed.

Examples From the F-15E

F-15E upgrades and future electronics innovations illustrate both near-term and future implications of such managerial and technical innovations.

These upgrades focused on three operational requirements: Make it break less, fix it sooner, and reduce the mobility burden. For instance, F-15 subsystems were ranked by field-reliability measures, which indicate when a subsystem failure results in an aborted sortie. Those subsystems with poor field-reliability measures became candidates for upgrading. With such new subsystems as the APG-70 radar, ring-laser gyro, and solid-state engine monitor display, the F-15E is projected to have twenty percent better reliability than the F-15C/D.

It will also be possible to put the F-15E back in the air sooner if a failure occurs. Analysis of the weapons carriage scheme shed light on some real time-savers. By using fixed instead of removable weapon stations pylons, it became possible to dispense with an entire C-141 load of extra parts and equipment and to avoid significant maintenance man-hours during weapons reconfiguration. A redesign of the Conformal Fuel Tanks (CFTs) permitted access to the high maintenance components without CFT removal. Finally, Built-in Test (BIT) has the potential to help reduce the chronic sortie-stoppers



The warranty program takes the view that any maintenance action counts as a failure. Failure to meet warranted minimum performance levels invokes delivery of consignment spares while repairs are made. This avoids loss of combat capability in the meantime. As this chart shows, between April 1982 and April 1984, the LN 39 standard navigation units for the A-10 did not meet the standards of the warranty, and consignment spares had to be issued. Since April 1984, the units have met and exceeded the reliability requirement and are now up to near 800 hours' mean time between failures.

described as Could Not Duplicate/Retest OK (CND/RTOK). The payoff will be speedier and more accurate "on-aircraft" troubleshooting, with the F-15E getting back on the flying schedule faster.

Salty Demo exposed our extensive reliance on fixed combat support equipment in avionics intermediate shops. A portable Mobile Electronic Test Set (METS), based on US Marine Corps equipment, is an interim answer to this situation for new F-15E electronics. Small and two-man portable, the METS contrasts sharply with AIS stations, which must be moved by forklift. Furthermore, METS is five times more reliable, processes broken systems six times faster, and doesn't require stringent environmental controls. As a result, better support is provided by more mobile equipment.

In these ways, the F-15E system gains additional flexibility by cutting its dependence on vulnerable combat support logistics. Such upgrades now and in the future will deny our adversaries those "unexpected routes and unguarded spots."

Transformation on the Ramp

A remarkable transformation is in progress as upgrade programs revitalize the combat capability and staying power of such older systems as the B-52 and F-111 and such newer ones as the F-15 and F-16. C^3I systems are being improved in similar ways. Line-replaceable units exhibiting ten to 100 hours of reliability are being replaced by electronics that achieve thousands of hours of reliability through VHSIC technology. Aircraft ring-laser gyros provide for reliability up to ten times that of a spinning mass inertial gyro. Installation of the On-Board Oxygen Generating System (OBOGS) on the F-15E eliminates dependence on vulnerable LOX-generating plants and storage tanks. It also reduces mobility and manpower requirements. Along with the glamorous enhancements, ongoing PRAM (Productivity, Reliability, Availability, and Maintainability) initiatives continuously improve the overall R&M of systems on the ramp. Simple things, such as replacing a soft seal on infrared cooling systems, can, in this case, increase reliability fivefold while saving $14 million over the system's life.

Modifications that pair today's technology with yesterday's airframes extend to a varied mix of aircraft dating back to 1963. Many of these older systems will still be with us twenty years from now. Yet some of the original design technologies—avionics, engines, and structures—are from the 1950s and 1960s. AFLC and AFSC, in coordination with the operating commands, have been steadily improving the overall readiness and sustainability of this fleet. Several examples will illustrate the story.

The first concerns the modular air data computer, which converts analog pressure and angle of attack information to digital airspeed and attitude inputs used by numerous on-board avionic systems. In early 1981, AFLC item managers determined that the air data computers on various aircraft were unreliable and becoming unsupportable. To correct this situation, the Air Logistics Center at Oklahoma City, Okla., began the search for a reliable modular air data computer for use on several types of aircraft. A competition was held, and GEC Avionics Ltd. won with a system now called the

The portable Mobile Electronic Test Set (METS) is an interim solution to the AIS stations, which must be moved by forklift. The METS doesn't require strict environmental controls and is far more reliable than the AIS, and the newer equipment provides better support than equipment used previously.

Standard Central Air Data Computer (SCADC). Reliability has been increased tenfold, leading to the spares requirements being slashed to less than one-fourth of what was needed for the old air data computer. We also project a procurement savings of $43.6 million.

But the story does not stop here. The contractor guaranteed the 2,000-hour Mean Time Between Failure (MTBF). As part of this guarantee, the contractor will provide consignment spares based on the achieved MTBF, measured quarterly during the guarantee period. At the end of the guarantee period, any calculated spares become property of the procuring activity. Additionally, the contractor may submit no-cost ECPs in order to achieve the desired reliability. This approach avoids degrading combat capability while motivating the contractor to identify and fix design flaws.

The Bottom Line

The bottom line: Air Force operators now use SCADCs that are much more reliable than the old ADCs, which decreases projected field failures and thus substantially decreases required spares. Increased reliability means aircraft break less often, increasing combat capability while freeing monies for other defense uses.

The SCADC processes information conveyed to it via electronic signals. Some computing systems and microprocessors of today—and certainly those of tomorrow—require transmission rates that exceed electrical capabilities. In time, fiber-optics technology will move communication from electrons to light. Fiber optics will offer not only increased bandwidth over existing communication lines but also advantages in R&M and increased combat capability.

For example, in ground communication, such systems as the 407L are burdened with heavy coaxial cabling, with its attendant limitations in cable transition lengths. A typical 600-foot coaxial cable weighs about 400 pounds. The same length of fiber-optic cabling weighs only about eighty pounds and takes up considerably less space. The real advantage, however, is that the fiber-optic cable can reach out more than 6,000 feet, thus allowing dispersal of the control vans from the antenna and taking the people away from the potential hazard areas. The transition will be achieved with a fiber-optics "radar remoting kit."

Not all information paths must be lengthy to take advantage of photon-encoded information, though. A new flare-and-chaff system deployed on A-10 and F-111 aircraft demonstrates the dramatic gains of this new technology. The original system, designed with 1960s technology, suffered from corrosion and inadvertent activation at inopportune times. The primary culprit turned out to be electromagnetic interference (EMI), with external signals coupling into the copper coaxial cabling.

Traditional methods for correcting this problem would have included shielding and filtering, which, in turn, add new problems of complexity and weight. In this case, a novel approach was taken. Boxes were redesigned and linked via fiber optics, which are immune to EMI. The number of system boxes decreased from forty to twenty-eight, primarily as a result of using fiber optics. Of much greater significance, the new system has been flown on test missions without a single failure.

Downstream, we can envision internal data transmission rates 1,000 times greater than what's possible with conventional copper coaxial cable. Systems will be freed from the heavy shielding and filtering components necessary for EMI and nuclear-induced electromagnetic pulse (EMP) protection. Equally important, fiber-optic transmission lines will function one hundred times longer than copper co-ax.

Transmittal Takes Many Forms

Information transmittal takes many forms. Hydraulic systems, for example, convey information through differences in hydraulic pressure. But present central hydraulic systems pose several problems, ranging from the use of high-pressure/low-viscosity fluids (to reduce the risk of fire) to extensive vulnerable plumbing. Research into electrohydrostatic activation systems holds the promise of a day when hydraulic lines may become an obsolete mode of information transmission.

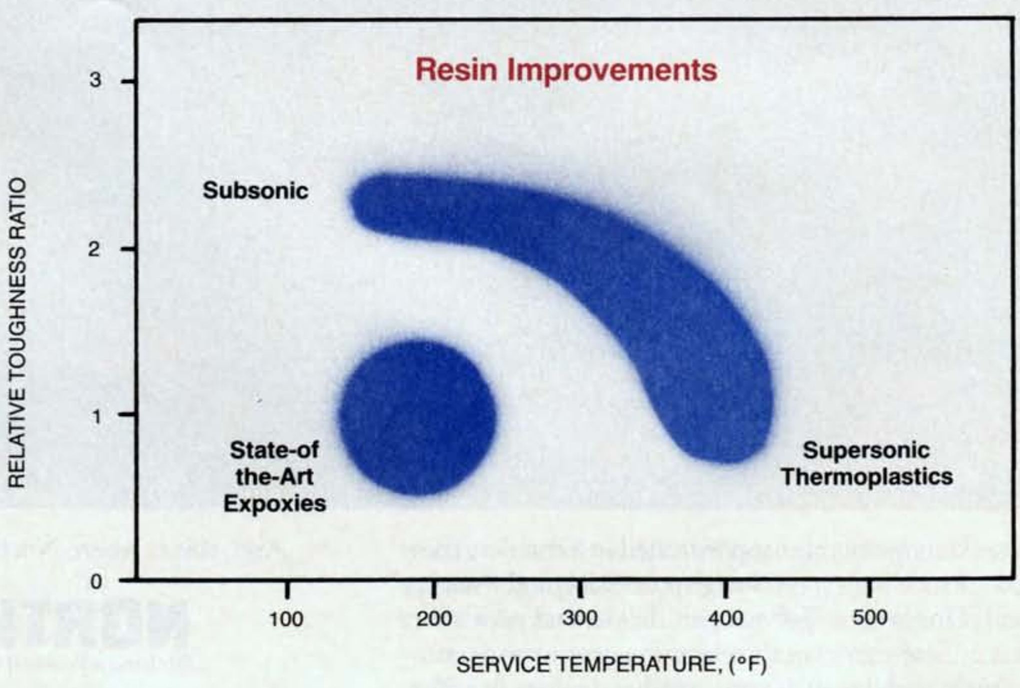
These self-contained flight-control actuators could receive pilot-initiated control inputs transmitted over fiber-optics pathways. Synergistic fallout from this combination will include reduced cost, size, and weight. And, as with so many applications of new technologies, systems built this way should achieve significantly higher R&M than their predecessors. Prototypes show a threefold improvement in actuator reliability while concurrently eliminating maintainability headaches associated with hydraulic lines and couplings.

External advances in structural materials also hold great promise. Several aerospace firms, including Boeing, are already realizing the potential of advanced thermoplastic composites. This material is not some researcher's dream. Low-temperature thermoplastics will be used extensively in the Navy's A-6 Replacement Wing Program.

The material has many unique properties. The thermoplastic resin matrix, which holds the graphite filaments, can be repeatedly softened and hardened. This contrasts with such thermoset composites as graphite epoxy, whose molecules are irreversibly crosslinked. As a result, maintenance and repairability will be enhanced through such techniques as electromagnetic welding, resistance welding, and hot-knife lamination. The service lifetimes of wings and other systems will be extended, too. For example, the A-6 wing's estimated useful life will jump from about 2,000 flight hours to 8,800.

Because of weight, toughness, repairability, and other

Current research indicates that thermoplastics (synthetic materials that can be repeatedly softened by heat and rehardened) can be extended into the high-temperature supersonic regime. In the temperature realm of supersonic flight, conventional epoxies fail. Thermoplastics, however, retain their integrity well beyond temperatures induced by supersonic heating. "Supersonic thermoplastic" is a candidate material for the Advanced Tactical Fighter.



attributes, thermoplastics will be employed increasingly in the future. Thermoplastics have almost twice the toughness of state-of-the-art epoxies at wing temperatures generated by the A-6 in subsonic flight. Current research indicates that thermoplastics can be extended into the high-temperature supersonic regime. In the temperature realm of supersonic flight, conventional epoxies fail. Thermoplastics, however, retain their integrity well beyond temperatures induced by supersonic heating. This property, among others, makes "supersonic thermoplastic" a candidate material for the Advanced Tactical Fighter (ATF).

Future uses of the material will certainly appear if accelerating corporate expenditures are any indication. Boeing Corp. alone increased its investment in this field by more than 700 percent between 1982 and 1986.

Another technology that lends itself to big gains in R&M and combat capability is Very-High-Speed Integrated Circuitry, or VHSIC. An example of such an upgrade is the Programmable Signal Processor (PSP) in the APG-68 radar of the F-16 fighter. Progress thus far on this PSP shows an increase in reliability of ten times, thus achieving the Air Force's new standard of 2,000-hour MTBF for avionics. We can now foresee the possibility of detecting and isolating faults in Shop Replaceable Units (SRUs) of the entire radar system without the use of intermediate-level maintenance test equipment.

VHSIC technology, when applied to this PSP, will allow enough room in the original box for new modes and electronic counter-countermeasures in the future. We estimate that the PSP will save about $100 million in acquisition costs and yield life-cycle savings of $200 million.

Capability: Time After Time

Today, smart applications of new technologies are increasingly making it possible for weapon systems to get the job done, time after time, with minimal maintenance.

Composite materials extend the life of highly stressed structural members of aircraft. Breakthroughs in engine design make reliable high-thrust engines a reality. Very few areas, however, have changed more radically than electronics. We will soon see the first totally integrated avionics suite, integrating fire-control, flight-control, and propulsion systems. Concurrent with increased performance, this suite will elevate reliability and maintainability to unprecedented levels. Behind these advances are the Very-High-Speed Integrated Circuitry (VHSIC) and Microwave Millimeter-Wave Monolithic Integrated Circuits (MIMIC) programs.

We envision chips with 100 MHz speed and capacities of 30,000,000 devices. Chips with these densities bring immediate improvement in reliability by reducing the number of interconnects. In fact, 25,000,000-hour VHSIC chips are already the norm.

These mind-boggling statistics only hint at the revolution just around the bend. First, VHSIC chips are so capable that a single "circuit card" bearing different standardized chips will contain all the circuitry necessary to perform a complete digital data or signal-processing function. This single card will fit in your hand. You can build up a set of thirteen such cards, which individually perform such functions as processing, bulk memory, and interfacing. These common cards can then be appropriately integrated to form ECM or radar processing systems. Finally, systems composed of common and standardized cards will be tied together under the Pave Pillar architecture. Suddenly we have highly reliable, standardized VHSIC cards that can be exchanged among functional systems.

The Integrated Communications Navigation Identification Avionics (ICNIA) illustrates the improvements resulting from VHSIC line-replaceable modules. Currently, the combined reliability of the separate systems works out to approximately forty hours. However, ICNIA's reliability will jump to more than 4,000 hours—with the potential to reach more than 10,000. We gain not only this phenomenal increase in reliability but also project that costs will drop by fifty percent.

Even if a module in the ICNIA suite does fail, the system instantly switches that function to a different module, any number of which are capable of taking over. Depending on the circumstances, the system may signal a human operator to choose priorities among functions the rerouted system must perform, but the weapon system itself has "fail-soft" redundancy. The mission continues, even with a key communications processor on the blink. That's combat capability.

Furthermore, accumulated history of avionics failures will make it possible to know when a module enters the zone of probable failure so that it can be replaced before it goes out.

A New Age

We stand at the threshold of the third generation of avionics systems. VHSIC, built-in testing at the chip level, common modules, "fail-soft" distributed redundancy, and estimated remaining useful life—all these go to form the Modular Avionics Systems Architecture (MASA). Now the practice of using electronic components until they fail can be eliminated. Aircraft equipped with MASA systems should rarely experience in-flight avionics failures for reasons other than battle damage.

The impact on combat capability of MASA and upgrade programs such as those seen with the F-15E becomes clear. We could fill pages with the cascading effect. We are about to enter a new age: improved system performance over time and reduced combat support.

With full adherence to the goals of the R&M 2000 initiative, the Air Force will turn Sun Tzu Wu's warning about unreadiness, unexpected routes, and unguarded spots to our full advantage. Even in the face of a very fluid battlefield, where the Forward Edge of the Battle becomes ill-defined, our forces will possess the flexibility, mobility, and staying power necessary to carry the day. The challenge lies before us, and the way is clear. ■

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