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COL ANTHONY C. CAIN, EDITOR

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Emerging Air and Space Power Technologies

THE FULL RANGE of air and space power capabilities is inherently tied to technology, more so than any other form of military power. Although navies most closely approximate air and space forces in this relationship, the capabilities resident in sea forces matured in the industrial age and are constrained by the physical challenges of operating on and beneath the surface of the world's oceans. Air and space power also originated in the industrial age, but technological advances and the potential to expand its operational capabilities uniquely equip this form of power to bridge conflicts between the industrial and information ages.

The problem with any institution that relies so heavily on technology is that leaders and practitioners have to balance present needs, doctrinal requirements, and strategies for future innovation. On the one hand, the lure of new technology can encourage a fascination with gadgets that ultimately reduces the application of air and space power to a tactical level. On the other hand, airmen might have to forgo research into new technological areas because of the expenses that invariably accompany innovation. In the 1920s and 1930s, airmen struggled with both of these constraints on technological change. They ultimately created a doctrine and strategy for employing airpower that helped define technologies—the long-range bomber and precision bombsight—required to execute the strategy. In the absence of fiscal resources and clearly defined threats, members of the interwar generation laid a doctrinal foundation for employing airpower in the event of another war between the great powers. In their dogged pursuit of doctrine, however, they failed to anticipate requirements for long-range fighter escorts, thus illustrating how the balancing act requires constant attention and investment.

Presently, US Air Force members do not have the freedom to develop doctrine gradually. The global war on terrorism; ongoing operations in Iraq, Afghanistan, and elsewhere; conventional and unconventional threats to states; and the imperative to protect the homeland dictate heightened operations tempo and command vast resources. These factors can militate against researching and introducing new technologies. Therefore, air and space professionals must pay careful attention to identifying future requirements and capabilities that serve as catalysts for the next generation of technological advances.

Our Air Force must recruit innovators who can transform the technological superiority we now enjoy into even more impressive capabilities that prepare us to meet future threats and challenges which we cannot imagine today. As in the interwar period, doctrine, operating concepts, and organizational structures must also evolve in anticipation of emerging technological capabilities to ensure that all components of air and space power come together precisely at the right time and place. This was the challenge for the airmen of yesterday, and it will remain so for air and space forces of the future. □

What We Believe

Air Force doctrine has evolved from an informal, largely oral tradition of tenets to the present comprehensive system of doctrine documents. Clearly our service needed more rigor than was contained in the Cold War versions of Air Force Manual 1-1, but why have air and space power professionals opted for a doctrine structure that contains 37 separate doctrine documents, including such subjects as *Leadership and Force Development* (Air Force Doctrine Document [AFDD] 1-3), *Health Services* (AFDD 2.4-2), *Education and Training* (AFDD 2.4-3), and *Legal Support* (AFDD 2.4-5)?

Institutions publish formal doctrine for at least two audiences. The primary audience of formal Air Force doctrine is internal—airmen. Members of our institution must have access to and be well grounded in our commonly held beliefs. Airmen must also be able to effect change to those beliefs through alteration, deletion, and addition to existing doctrine. The second audience for formal institutional doctrine is external—individuals, groups, and institutions outside the Air Force. They gain knowledge of our values, beliefs, capabilities, and organization through our formal published doctrine. These secondary audiences typically benefit from our institution's capabilities and services but lack the background, training, and infrastructure to provide or accomplish those things themselves. Therefore, published doctrine allows external audiences to smoothly integrate their inherent capabilities with ours, without having to spend the effort, time, and resources necessary to duplicate those capabilities in their own institutions.

Not all doctrine shares the same purposes. Just as warfare may be examined along a spectrum that spans strategic, operational, and tactical activities, doctrine also functions at various levels. *Basic Doctrine* (AFDD 1 series) communicates fundamental institutional beliefs that derive from historical experiences. It is a record of ideas and concepts that worked and those that didn't when airmen employed air and space capabilities; it is also a common frame of reference when discussing the best way to prepare and employ air and space forces, shaping the manner in which our Air Force organizes, trains, equips, and sustains its forces.

Operational Doctrine (AFDD 2 series) communicates how the Air Force translates basic doctrine's fundamental beliefs into practice through organizations and distinct capabilities. *Tactical Doctrine* (AFDD 3 series) outlines force-employment principles that allow the institution to accomplish specific objectives. When considered as a whole, the three levels of doctrine allow air and space professionals to understand and forge links between strategic, operational, and tactical levels of war.

Without constant attention, doctrine may degenerate into dogma. This observation cuts to the heart of what professionalism means. Practitioners—airmen—have a responsibility to reinvigorate their doctrine with new ideas from two sources. First, and perhaps most importantly, is an understanding of historical and recent experience. Because doctrine is an accumulation of knowledge, each new operational experience should present opportunities for its revitalization. Second is doctrine's characteristic of embracing forward thinking. In other words, doctrine should not be a formula to be applied by rote; rather, it should become a catalyst for developing new concepts, organizations, and capabilities appropriate to future challenges. In this sense, current doctrine becomes a source—an outline, a forecast, or a guide—on which future doctrine can be developed. Basic doctrine is perhaps the fundamental outlet for this second aspect. It is broadly written, and the concepts therein may provide momentum and justification for technological and organizational innovation.

Doctrine represents what is institutionally believed to be the best way for professional airmen to employ air and space power to serve the national interest. One measure of the maturity and the health of professional military institutions is their published formal doctrine. The health of those institutions reflects the importance that their members place on knowing, applying, challenging, and revising the ideas contained in their doctrine. The institution's maturity, then, is the direct result of the scope and rigor of the members' investment in their doctrinal structure. In other words, published doctrine does not relieve airmen of the requirement to think—on the contrary, it provides an institutional mandate and a forum for continuous professional improvement.

To Learn More . . .

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine*, November 17, 2003. https://www.doctrine.af.mil/Library/Doctrine/afdd1.pdf.

Boyne, Walter J. *The Influence of Air Power upon History*. Gretna, LA: Pelican, 2003.

Futrell, Robert F. *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force*. 2 vols. 1971. Reprint, Maxwell AFB, AL: Air University Press, 1989.

Holley, I. B., Jr. *Ideas and Weapons*. 1953. Reprint, Washington, DC: Office of Air Force History, 1997.

Conflicts, no doubt, will be carried on in the future in the air, on the surface of the earth and water, and under the earth and water.

—Gen William "Billy" Mitchell

The Effect of Human Factors on the Helmet-Mounted Display

MAJ JAMES R. VOGEL, USAF
DR. MARIAN C. SCHULTZ
DR. JAMES T. SCHULTZ*

IN WORLD WAR I, the mounting of machine guns on airplanes marked the official beginning of the evolution of pilot-centered weapons employment. The technological advancement of combat aircraft and pilot-to-vehicle interface has enjoyed steady growth throughout the history of these aircraft. Following the innovation of the mounted machine gun, the development of both airborne radar and the infrared search-and-track system allowed fighter pilots to cue their weapons beyond the bore line of the airplane.

In most fighter aircraft, the field of view of these two cueing systems is approximately plus or minus 60 degrees off the aircraft's bore line. Although both systems are very important to one's ability to use weapons beyond visual range, the employment of heat-seeking missiles and modern machine guns still requires the pilot to point the nose of the fighter jet at the target. Consequently, fighters can find themselves engaged in long-turning fights, thus becoming vulnerable to both the aircraft with which they are engaged as well as other enemy aircraft in the area—a deadly scenario.

Introduction of the head-up display (HUD) marked the first step toward allowing pilots to cue their missiles or guns with an out-of-the-cockpit aiming device. A giant leap forward in terms of pilot-to-aircraft interface, the HUD displayed not only accurate weapons-aiming symbols, but also

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relevant flight data such as airspeed, altitude, and heading (fig. 1). For the first time, pilots could view such information without looking back inside the cockpit.

Currently, the development of high off-boresight weapons is driving the latest work in pilot-centered weapons employment. Many foreign air forces already have this capability, and a number of others are acquiring it. Dean F. Kocian of the Air Force Research Laboratory's Human Effectiveness Directorate addresses the evolution of high off-boresight weapons and their dramatic impact on fighter aircraft:

> Since the mounting of machine guns on airplanes in World War I, pilots have pointed the nose of their aircraft in the direction of the target. The dynamics of airborne combat required pilots to outmaneuver each other. Superior aircraft speed and agility were the keys to a successful engagement; however, that scenario has changed. . . .
>
> This scenario represents a total paradigm shift in the way air-to-air combat is fought. The sighting reference for cueing a weapon is no longer the nose of the aircraft, but rather the pilot's helmet. As long as the target is within visual range and the pilot can view the target through the display in the helmet visor, the relative position of the aircraft to the enemy is not critical, but tactical implications are profound.[1]

In order to cue high off-boresight weapons to the target in a visual dogfight, pilots must have a helmet-mounted aiming device, which itself represents a human-factors breakthrough. Since the beginning of aerial combat, air forces around the world have run a technological race aimed at gaining superiority through increased propulsion and maneuverability of fighter aircraft. But these new levels of performance can take a toll on humans. For example, pilots subjected to high-G forces risk loss of consciousness and extended incapacitation; however, the helmet-mounted target cue and high off-boresight weapons enable the missile, capable of more than 50 Gs, to execute the high-G turn instead of the pilot.

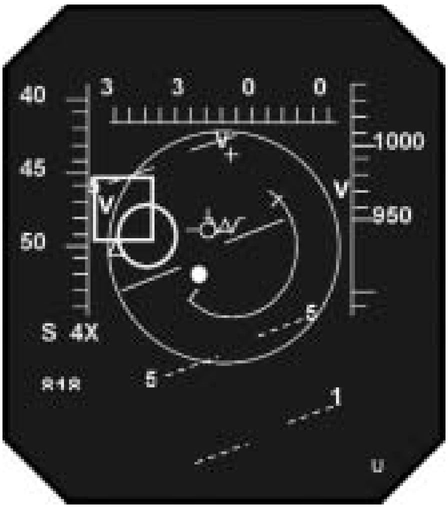

Figure 1. An F-15C's HUD. (Reprinted from Maj Reid Cooley, briefing, subject: Joint Helmet-Mounted Cueing System, 422d Test and Evaluation Squadron, Nellis AFB, Nevada, June 2001.)

Development of the Helmet-Mounted Display

The United States Air Force has worked on a helmet-mounted display for fighter aircraft for roughly 30 years. The proliferation of various types of high off-boresight weapons by enemy countries lends a sense of urgency to fielding this capability as soon as possible. Indeed, the fact that the Air Force is not holding on to the leading edge of this technology places our combat capability in the visual environment at risk. Less proficient pilots flying inferior aircraft enjoy a distinct advantage because they have a helmet-mounted display system.

The Russian MiG-29 Fulcrum and its AA-11 Archer high off-boresight, heat-seeking, short-range missile are considered the primary threat in the visual environment. MiG-29 pilots acquired helmet-mounted cueing devices for use almost a decade ago. Even though they are rudimentary, using only a flip-down aiming monocle and lacking missile-cueing symbols, they give the Russians a tremendous advantage in visual dogfighting. Ironically, the Israeli air force, which purchases its F-15 and F-16 fighter jets from the United States, also outpaces us in this arena because it has fielded a display and sight helmet (DASH) for those aircraft.

Essentially, helmet-mounted displays are "must have" equipment on fourth-generation fighter aircraft since high off-boresight weapons and visual cueing outweigh any aircraft-performance advantage in dogfighting. For that reason, the Air Force and Navy are currently in the process of acquiring and fielding the Joint Helmet-Mounted Cueing System (JHMCS), the most advanced such system in the world (fig. 2), which—together with the AIM-9X high off-boresight, short-range, heat-seeking missile—will soon allow the United States to regain the advantage in aerial combat.

Vista Sabre II, the JHMCS's initial prototype, provided a building block for helmet-display development. Several helmet-mounted trackers and displays had emerged parallel to the Vista Sabre program, but significant performance or safety problems limited their utility. In conjunction with the 422d Test and Evaluation Squadron at Nellis AFB, Nevada, Vista Sabre II performed the initial operational-utility evaluation, beginning in 1993. Kaiser Electronics produced the electronic components and helmet

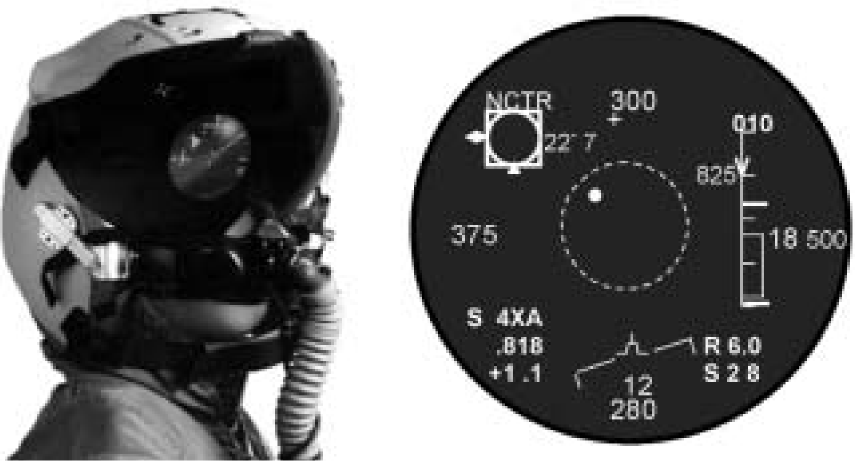

Figure 2. JHMCS helmet and display. (Reprinted from Maj Reid Cooley, briefing, subject: Joint Helmet-Mounted Cueing System, 422d Test and Evaluation Squadron, Nellis AFB, Nevada, June 2001.)

hardware, while McDonnell Douglas's software engineers developed the operational flight program for the F-15's computer, which would allow the helmet-mounted displays to function and interface with aircraft-weapons information.

The evaluation uncovered several important human-factor or "liveware"-to-hardware issues related to helmet cueing and the employment of off-boresight weapons. The first concerned the problem of poor helmet fit and its effect on helmet-display performance. Although the new helmet-mounted display hardware was incredibly light, the center of gravity and increase in relative weight under nine-G loads tended to shift the helmet on the pilot's head during high-G maneuvering. Because a magnetic field in the cockpit of the aircraft senses the position of the helmet and feeds the current line of sight from the helmet to the aircraft's flight computer, any such shifting would generate errors, thus making the accurate pointing of the missile seeker at a target nearly impossible. Specifically, the Vista Sabre II test found that static pointing errors of more than two degrees could render aiming capability ineffective.

The evaluation also noted the inability of pilots to hold their heads steady during high-G turns and aircraft buffeting, the latter designating the shaking sensation one feels when the aircraft performs at the edge of the flight envelope during a high angle of attack. Vista Sabre II revealed that the system needed interface suppression to smooth head bounce during high-G maneuvers and in regions of aircraft buffeting. Otherwise, the pilot's ability to aim with the helmet is severely degraded.

Furthermore, in a finding referred to as "eyeball critical sensor," pilots expressed concern over reflections and glare associated with the helmet display. Early visors had a noticeable "patch" that enhanced contrast and created a more discernable display—vital to sustaining good vision and, therefore, flight safety. Clearly, the Vista Sabre II program proved most effective in establishing a starting point for the evolution of helmet-mounted displays.

The Visually Coupled Acquisition and Targeting System (VCATS), the follow-on system to Vista Sabre II, made its inaugural flight in February 1997, successfully bridging the gap from the prototype helmets of the earlier program to today's JHMCS helmets. The VCATS targeted problems revealed by Vista Sabre II's operational utility evaluation. For example, it implemented the custom of equipping helmets with space-age gel liners and ear cups in order to achieve the fit required for optimum cueing performance. Moreover, the VCATS helmet visors were custom ground to fit precisely around the mask and lock into place, creating more stability and helping eliminate glare from under the visor, while tracker algorithms and more precise system integration nearly eliminated static pointing errors discovered in early helmet tests. The VCATS also implemented high-update-rate trackers, accelerometers, and digital-filter algorithms for active noise cancellation, vastly improving head bounce under high-G loads and aircraft buffeting. In order to combat the eyeball-critical-sensor issues, the VCATS removed the visor patch and utilized "hot-tube" cathode-ray-tube technology to reduce glare and increase contrast in the visor display. In general, the VCATS system successfully overcame the problems revealed by the early Vista Sabre II test.

In addition to taking on problem areas unearthed by Vista Sabre II, the VCATS also integrated the helmet-cueing capability into the "hands on throttle and stick" (HOTAS) functions of the F-15—a compatibility critical to the pilot-centered interface with the helmet system. The system also ensured full compatibility with night operations; indeed, fighters throughout the world may soon see displays—typically projected on the helmet visor—in the field of view of their night vision goggles (NVG). In the case of the VCATS, testing has proven the compatibility with panoramic NVG (fig. 3).

The VCATS program proved itself invaluable to the development of the JHMCS and the advancement of helmet-mounted displays in the US military. According to Kocian,

> an outstanding example of human-centered design, VCATS advances the [Air Force's Human Effectiveness Directorate] mission to maximize the potential of Air Force warfighting personnel. The directorate's primary goal is to link, via human-system integration, technological advances in controls, displays, and information-handling with the military pilot's human factors including sensory, perceptual, cognitive, and motor capabilities; strength and anthropometrics; experience; and skills.[2]

Human Factors in Helmet-Cueing Integration

Despite the impressive track record of the VCATS, designers must face several human-factor issues prior to successfully fielding and employing

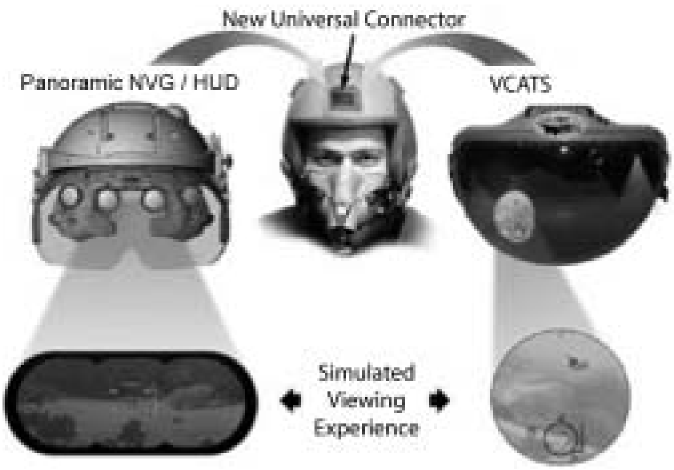

Figure 3. VCATS with panoramic NVG. (Reprinted from Lt Col Terry Fornof, briefing, subject: VCATS, 422d Test and Evaluation Squadron, Nellis AFB, Nevada, June 2001.)

the JHMCS. They must always concern themselves with maximizing the capability of the weapons available and ensuring the safety of the new helmet—especially during the ejection procedure.

First, early helmets did not take into account how often pilots use peripheral vision during a close-range dogfight. In general, while wearing helmets, they can turn their heads approximately 60 degrees from side to side of the aircraft's bore line. New technologies, however, confer upon fourth-generation missiles an off-boresight capability exceeding 60 degrees. In order to compensate for pilots' limited range of head movement, the JHMCS utilizes an "up-look" aiming reference (fig. 4). That is, two up-look reticles provide higher off-boresight cueing capability by allowing pilots to cue the missile with their peripheral vision. Thus, they can utilize the full capability of missile technology and successfully employ weapons beyond 60 degrees off boresight.

Figure 4. JHMCS peripheral-vision up-look reticle. (Reprinted from Maj Reid Cooley, briefing, subject: Joint Helmet-Mounted Cueing System, 422d Test and Evaluation Squadron, Nellis AFB, Nevada, June 2001.)

Second, the extra weight of the hardware in a helmet-mounted cueing display might present problems. Although engineers can make the units incredibly light, the operational environment for fighter aircraft is much more complex than the one G experienced here on Earth. Today's fighter pilots attempt to perform high off-boresight helmet cueing under loads up to nine Gs—nine times the force of gravity. But G effects are expediential rather than linear in nature. Since dogfighting pilots constantly move their heads to clear the flight path and maneuver to kill the adversary, having to endure extra weight with a slightly different center of gravity places a tremendous amount of force on their necks. This is a serious concern according to contributors to a panel discussion held at the Aerospace

Medical Association Annual Scientific Meeting in Detroit in May 1999, who mention how air forces around the world already lose a considerable number of workdays due to soft-tissue neck injuries. They conclude that these numbers will dramatically jump as more pilots begin to fly with helmet-mounted devices.[3]

Third, in addition to increases in neck injuries due to flying maneuvers, one must also consider the effect of additional helmet weight on the pilot during ejection, particularly the possibility of neck injury due to inertial loading with drogue and parachute deployment. Other problems could arise from an increase in helmet size and inattention to windblast.[4] Engineers and developers must balance capability against pilot safety, perhaps opting to decrease the maximum limits of maneuver aircraft if the pilot is equipped with a helmet-cueing system.

Finally, flying with JHMCS increases the potential for spatial disorientation as well as task saturation. Most fighter pilots are used to flying with HUD information, which is always in the same place relative to the airplane—on the bore line in the direction the aircraft is traveling. But flying with "HUD-like" displays on the visor can initially be disorienting because information is now located wherever they happen to be looking at the time. The problem is compounded at night due to the general lack of either a horizon or visual cues. Furthermore, having to keep up with aircraft parameters such as altitude, heading, and airspeed displayed directly in front of the right eye while attempting to employ and monitor weapons during dogfighting can quickly become overwhelming to pilots. To help lessen the danger of helmet displays contributing to this sort of task saturation, designers have enabled a HOTAS function so that pilots can blank the display if it becomes distracting in the tactical environment. Obviously, human-factor issues concerning helmet-mounted cueing systems should not be taken lightly. Awareness of these issues, along with proper education and training, can help prevent such problems from leading to tragedy.

Potential of Helmet Development

Helmet-mounted displays have evolved at a rapid pace over the last decade, and the future may hold even more technological advances for military helmets. Short-term improvement projects include voice commands and sound-direction recognition; long-range technological advancements might include imagery transmission and piloting by remote virtual helmets and cockpits.

The integration of sound into the next generation of pilot helmets seems inevitable, with several companies already developing and testing the use of voice commands. In fact, Robert K. Ackerman notes that voice commands will eventually take the place of HOTAS measures to provide rapid response to the demands of air combat.[5] Future pilots may also have the luxury of flying with a three-dimensional sound system within their helmet, currently under development for use in the French-built Rafale fighter. The system will provide direction-specific cues that alert pilots to the direction of the threat and that distinguish between different types of threats by means of various sounds.[6] Future US helmets for pilots of Joint Strike Fighters will feature night vision, sound, and other sensors.

Although the next giant leap in helmet technology might seem far away, one finds growing interest in pilots flying unmanned aerial vehicles (UAV) by wearing a helmet in a virtual cockpit and receiving images, just as they would if they were actually in the aircraft. Technological developments could overcome obstacles involving photo imagery, data transmission, and display, thereby enabling the rapid growth of UAVs.

Conclusion

Human factors and pilot-centered design in aviation have a long and colorful history, beginning with the mounting of machine guns on aircraft and progressing through advanced weapons displays on helmet visors. By recently conquering several technological problems, developers and engineers have enabled helmet-mounted display systems to become a viable and almost necessary part of fighter aircraft. The high off-boresight capabilities of today's fourth-generation missiles, along with the challenge of overcoming human limitations, are partly responsible for the growth of helmet-mounted cueing devices. We have also seen that this innovative system carries with it certain risks, such as spatial disorientation, task saturation, and ejection compatibility, that engineers and users must address. But the advantages of helmet-mounted displays and the possibility of adding refinements like sound integration and virtual control hold great promise for the future of this technology. □

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Notes

1. Dean F. Kocian, "Human-Centered Design Project Revolutionizes Day and Night Air Combat," no. HE-00-10 (Wright-Patterson AFB, OH: Air Force Research Laboratory, Human Effectiveness Directorate, 2001), http://www.afrlhorizons.com/Briefs/June01/HE0010.html (accessed August 13, 2003).
2. Ibid.
3. "Military Flight Helmets: Is Head Protection Still Important?" (panel discussion chaired by Lt Col R. Munson at the Aerospace Medical Association Annual Scientific Meeting, Detroit, May 1999), http://www.geocities.com/iamfsp/panel.htm (accessed September 19, 2003).
4. Ibid.
5. Robert K. Ackerman, "French Helmet Visors Clear the Skies for Combat Pilots," *Signal Magazine*, August 1996, http://www.us.net/signal/Archive/Aug96/French-aug.html (accessed August 13, 2003).
6. Ibid.

Whither High-Energy Lasers?

MAJ GEN DONALD L. LAMBERSON, PHD, USAF, RETIRED
COL EDWARD DUFF, USAF, RETIRED
DON WASHBURN, PHD
LT COL COURTNEY HOLMBERG, PHD, USAF*

IMAGINE AN ABILITY to execute speed-of-light attacks against enemy forces with massive bursts of photon energy, literally incinerating the intended target. The desire for such a weapon is not the exclusive result of an appetite nourished by Hollywood science fiction and action-movie cultures, nor is it even a recent phenomenon. Mankind has been intrigued by the concept of directing light against a target for a very long time, and the absence of today's advanced technology did not preclude dreams and fantasies of novel weapons. An incident in "ancient" history illustrates this well.

The story takes place in the coastal city of Syracuse on the southeastern shore of Sicily, an island located across the Messina Straits from the southwestern coast of Italy. During the year 213 BC—2,217 years ago—Syracuse was the home of Archimedes. He was in his 75th year and after spending many years in Greece had returned to Syracuse for his retirement. Marcus Claudius Marcellus, the Roman commander, began attacking Syracuse during the second Punic War with a fleet of over 50 quinqueremes, vessels that were propelled by five banks of oars and filled with soldiers armed with all kinds of devices to overcome the city walls. Hiero, king of Syracuse, asked Archimedes to design a defense for the city. Attack after attack was successfully repelled, largely through the use of the *mechanical engines* engineered by Archimedes to hurl stones and other objects against the attackers. Marcellus demanded surrender; otherwise he promised to burn the entire city and execute all the people—Roman style. Fortunately for Syracuse, Archimedes had a secret weapon up his sleeve.

The geographical location of Syracuse led Marcellus to attack by sea from the east. He also chose to attack at daybreak so the sun would be at his back and in the eyes of the Syracuse defenders, hindering them from detecting and tracking his fleet. However, this geographical orientation also proved advantageous to Archimedes since the fleet's approach would be at a well-defined, small angle from the position of the sun. Archimedes conceived of a defense that employed mirrors to reflect and focus the sunlight on the Roman ships as they approached the island. The energy's

*General Lamberson serves on several senior-level Air Force technical review and advisory panels and, while on active duty, was responsible for much of the Air Force's research, development, test, evaluation, and acquisition. Colonel Duff is the deputy for programs, Laser Systems Office, and Dr. Washburn is the program manager of the Relay Mirror Technology Program, Directed Energy Directorate, Air Force Research Laboratory, Kirtland AFB, New Mexico. Colonel Holmberg is chief scientist, Air University Center for Strategy and Technology, Maxwell AFB, Alabama.

flux—reflected and focused sunlight—was sufficient to set the ships' tarred-fir planks on fire. In their first recorded use, *relay mirrors* destroyed Marcellus's fleet.

Whether this story is real or just a fable will probably never be known.[1] However, it is known that although Syracuse—through Archimedes—won the battle, it soon lost the war. Marcellus landed his regrouped forces on the undefended western end of the island and captured Syracuse by land attack, unintentionally killing Archimedes in the process.

Nothing in the laws of physics would have precluded Archimedes from building and employing this extraordinary defensive weapon. Several experiments, some recent, have successfully demonstrated that even crude mirrors could concentrate sufficient energy to cause the storied effect. One experiment fitted an aiming device to bronze shields, traditional equipment for the soldiers of Syracuse, and was able to successfully focus the reflected sun's energy and set wood on fire at several hundred meters. However, what really matters is not whether the story is true, but rather that it has persisted for over 2,000 years, which demonstrates the attractiveness and importance of such a capability.

Military research into high-energy lasers for weapons applications traces its beginnings to the early 1960s. Since then, significant advances in laser-power production, target tracking, and beam control have been made.[2] Systems such as the Airborne Laser Laboratory (ALL) of the early 1980s demonstrated that laser systems staged on airborne platforms could destroy enemy missiles. Nevertheless, are we any closer to fielding that revolutionary new capability for the war fighter?

The answer is "perhaps so." How? When? The remainder of this article addresses the difficulty of transitioning new technologies to the war fighter and the importance of robust technology demonstrations for high-energy laser weapons systems. Additionally, it highlights two critical new-technology areas that will likely be the key to our long-term laser war-fighting capability.

Technology Transition

Consider the general problem of transitioning a new technology into war-fighting systems. The laser was invented in 1961, and high-energy devices were demonstrated several years later. The high-energy laser community is often criticized because there is not yet any production associated with high-energy laser weapons. It turns out that an extended period of incubation is true of most revolutionary technologies. Today we are all familiar with the rapid evolution of fielded computer technology and capability, but the transistor, which makes it all possible, was invented in 1940. Arguably, it was the 1980s before the accelerated development of computer technology really matured. The Air Force Scientific Advisory

Board, under Dr. Gene McCall, characterized this phenomenon in its *New World Vistas* study of 1995.[3]

Consider a new technology which doubles in some attribute, say "relative importance," every four years as shown in figure 1. It is interesting to see how the "relative importance" compounds over 40 years—three orders of magnitude (from 1 to 1,000) on the chart, with most of the acceleration being in the last few years. In fact, the first few years are barely distinguishable. This simple, nonlinear behavior seems to be a characteristic of many technologies; the computing world knows it well as Moore's Law. An example in the weapons field is the development and fielding of precision strike weapons. The first prototypes of these now-so-familiar weapons were available in the early 1960s, but maturation did not occur until after Desert Storm in the early 1990s.

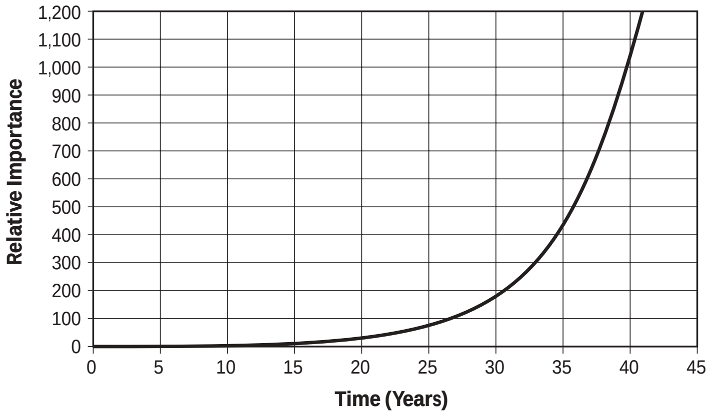

Figure 1. An attribute that doubles every four years demonstrates the effect of compounding, which is typical of many developing technologies.

Where would we place today's high-energy lasers on the chart of the hypothetical case just described? They are arguably somewhere around the knee of the curve, perhaps near the 30-year point. It is also plausible that the development of high-energy laser technology has nearly reached a point that, within the next decade, will enable most of the currently envisioned applications. Based on the simple exponential-growth analogy above, high-energy laser weapons are poised for a revolutionary leap. Whether or not US military interest in high-energy lasers actually accelerates these developments depends on many factors, not the least of which is the unfolding world situation and the demands and circumstances of the military operator. Although the research, development, and acquisition communities can neither predict nor control that requirement, the current trends of what the war fighter needs seem well entrenched—increased precision, rapid response, and tailored lethality to minimize collateral damage and reduce civilian casualties. What these communities can control and optimize is their readiness to transition high-energy laser weapons into production. The path to success is through mature and meaningful demonstrations on ground (mobile and fixed), naval, and airborne (tactical and strategic) platforms of interest.

Our recent experience is that today's US military is quite imaginative and creative in applying the weapons it has on hand, even the so-called hi-tech weapons. In fact, it is common for the military operator to find applications for weapons that the weapon developer never had in mind. However, the typical operator is neither well informed nor overly interested in revolutionary technologies that may satisfy his requirements. That is why technology demonstrations, or early system prototypes, are so crucial in capturing the interest and imagination of the operator. It is important that these demonstrators show not only that the physics, engineering technology, and integration issues are understood, but also that they provide operators with sufficient access to demonstrators to whet their appetite for a new operational vision. If that is marketing, so be it. Demonstrator systems of this class tend to be very complex and expensive; they take years to develop. After all, depositing significant energy with centimeter-like precision at ranges from a few kilometers to perhaps thousands of kilometers is a very complex task. There are, however, three such high-energy laser demonstrators in the works today.

Technology Demonstrators

The Army's Tactical High Energy Laser (THEL) (and its mobile variant), United States Special Operations Command's (SOCOM) Advanced Tactical Laser (ATL), and the Missile Defense Agency's (MDA) Airborne Laser (ABL) are the Department of Defense's (DOD) major laser-weapon-technology demonstrators.

The high-energy laser community owes much to the Army's successful demonstration of the THEL. The megawatt-class deuterium fluoride chemical laser, which lies at the heart of the THEL, is a very mature technology. It successfully engaged and destroyed several in-flight Katyusha rockets at ranges of several kilometers. The THEL's successful demonstration has attracted the attention of many who are interested in tactical laser weapons. As a spin-off of the original effort, there is now a program to develop a mobile THEL (MTHEL).

The ATL is the latest demonstrator to be defined and programmed. The ATL uses a closed-cycle, chemical oxygen-iodine laser (COIL) with an appropriate beam control. The closed-cycle system captures all of the waste by-products, making it suitable for tactical employment. The ATL will be installed in a C-130 aircraft to demonstrate its ability to engage tactical targets from a moving platform at ranges of approximately 10 kilometers. This SOCOM demonstration program is important and should be completed in the next three to five years.

The MDA's ABL program is the largest and most complex of the major high-energy laser demonstrators that the Air Force is executing. The ABL uses a very large COIL, and its components are integrated into the fuselage and systems of a Boeing 747-400 aircraft. It is designed to operate at very high altitudes (~40,000 ft) and have a capability to kill theater ballistic missiles (TBM) while they are still in their boost phase. The aircraft has been modified and flown to Edwards AFB, California, where its laser modules are being tested in a dedicated test cell. Its beam-control system is finishing a low-power checkout in Sunnyvale, California, before it is installed in the aircraft for low-power flight tests. Finally, the high-energy COIL will be installed on the aircraft for full system integration and testing. These efforts should be completed in about two years.

To propagate and focus laser energy over a distance of hundreds of kilometers and through the atmospheric turbulence that exists above 40,000 feet requires a robust atmospheric compensation or correction system for the laser beam. An adaptive-optics technology system has been built and shown to achieve good results at low power, but not yet at high power. The ABL, therefore, remains the major demonstrator by which to judge the maturity of US high-energy laser-engineering knowledge.

The success of these demonstrators will directly affect not only the transition of laser weapons into production but also the prospect of more advanced applications. One can anticipate a "window of opportunity" to open with the success of the ABL, ATL, and MTHEL, which will define high-energy laser-weapon activities for some time to come.

New Technology Highlights

This article limits itself to discussing electric solid-state lasers and relay mirrors. These topics, because of their extraordinary importance, deserve emphasis before all other high-energy laser-technology research.

Laser-Technology Maturity

Before this article launches into the benefits of solid-state lasers, it is useful to understand the technological maturity of high-energy lasers in general—both chemical and electric solid-state. Researchers know very well how to generate megawatts (MW) of laser energy with the gases from chemical lasers. With chemical oxygen-iodine and deuterium-fluoride lasers, we can also get suitably high-quality beams at full power. It is no accident that all three of the demonstrators discussed previously use chemical lasers. Currently that is the only way to achieve an excess of 10 kilowatts (kW) of average power, which is required for the desired effects on targets. So it is reasonable to assume that chemical lasers will be the engines of choice for large, strategic, high-energy laser applications requiring laser powers on the order of a megawatt (MW or 10^3 kW). Numerous studies have been conducted that suggest tactical applications of high-energy lasers become relevant at around the 100 kW level.[4] For power levels in this range, solid-state lasers have clear advantages when compared to chemical lasers, which include being able to avoid the difficult challenge of providing and disposing of hazardous chemicals during battlefield operations. Neither is it clear that chemical gas lasers can be efficiently packaged for the small volumes associated with trucks or fighter aircraft.

Electric Solid-State Lasers

Although significant challenges exist, electric solid-state lasers have great potential and are very attractive for tactical applications. Since we are already accustomed to generating and distributing electrical power on our platforms to run various subsystems, the logistics of electric solid-state lasers appears much more simple and attractive than that for chemical lasers. An "unlimited magazine," where a laser-weapon platform has "laser bullets" as long as it has fuel, is also very appealing. Likewise, it appears that solid-state lasers can be more efficiently packaged. Currently, the maximum power achieved by solid-state lasers is around 15 kW with relatively poor beam quality. Scaling these lasers to attain a system with higher power and high brightness is a significant challenge. A major joint effort is under way to demonstrate the nation's first weapon-class tactical laser small enough to fit on board combat aircraft, ground vehicles, and naval vessels.

The DOD High Energy Laser Joint Technology Office in Albuquerque, New Mexico, is leading the Joint High-Power Solid-State Laser Development Program with significant participation from industry and each of the services. The Program Research and Development Announcement (PRDA), dated August 2002, stated that the goal of the program is to demonstrate and deliver a 25 kW–class solid-state laser by December 2004. The PRDA also emphasized system characteristics such as beam quality, size, weight, efficiency, reliability, and ruggedness as key factors in establishing a scalable design path for a 100 kW system capable of integration onto tactical platforms. These goals are challenging and even more so on the prescribed schedule. Raytheon Company in El Segundo, California, and Northrop Grumman Space Technology in Redondo Beach, California, each won contract awards to pursue separate and distinct approaches. Additionally, the DOD selected Lawrence Livermore National Lab's solid-state heat-capacity laser program, sponsored by the Army, to join in the competition.

Relay Mirrors

Once these demonstrations establish the feasibility of high-energy laser weapons, the next question becomes, How can their range be extended? Atmospheric absorption, atmospheric turbulence, and curvature of the earth all limit the full potential of high-energy laser weapons. To compensate for these limitations, developers could build larger, more powerful lasers; use larger primary telescope optics; or attempt to place the laser system on high-flying platforms or even in space. For a given platform, however, the volume and weight constraints are likely to be very limiting. Researchers should continue to increase the brightness of the laser beam through more advanced beam-control techniques, and not solely for increased range. Nevertheless, this technique also is limited. As the performance of high-energy laser systems continues to improve on the margins, relay-mirror configuration could be another range-boosting option to consider.

Relays are not a new idea—Archimedes used a relay optic with solar power as a weapon. The Strategic Defense Initiative Office also considered relays in the early days of missile defense. However, at that time, the poor laser-beam quality that researchers were able to transmit to the relay system was a critical limitation. Researchers at the Starfire Optical Range, a division of the Air Force Research Laboratory's (AFRL) Directed Energy Directorate at Kirtland AFB, New Mexico, have been diligently working that issue for some time and now know how to solve that problem. Scientists use a cooperative beacon and adaptive optics in the source-to-relay uplink to sense and then minimize atmospheric aberration. Therefore, a bifocal relay mirror effectively puts the laser source at the mirror. This dramatically increases system brightness and intensity on the target at a constant range or extends the laser's range to a target while retaining the original levels of brightness and intensity. The implications of this are easy to understand.

The separation of the laser source from the beam-directing system allows each subsystem to operate in its most advantageous environment. In addition to the substantial range extension, technologists are just now beginning to understand the system flexibility such separation allows. The heavy, high-energy, and illuminator laser sources can be kept on the surface—ground- or sea-based platforms—far removed from the actual fighting, easing maintenance and allowing for the generation of beams with higher power. The optical relay system will be above most of the atmosphere, minimizing the adverse effects caused by atmospheric turbulence. Additionally, a single laser using a network of multiple mirrors could overcome horizon limitations and generate alternate line-of-sight paths to attack targets occluded by clouds or other obstacles. Some relay-platform concepts include networking multiple lasers for a single relay that can be pushed forward in the battlespace and occupy the high ground, essentially loitering in a geostationary position high above an area of interest.

When one previously considered the advantages and disadvantages of relay-mirror systems on various host platforms—manned aircraft, unmanned air vehicles, and even high-altitude airships—satellite relays were likely to have been seen as the most advantageous. However, the advent of MDA's High-Altitude Airship (HAA) program now allows one to consider additional trade-offs when deciding to locate a relay-mirror system in space or on an airship. Relays mounted on a space-based platform offer the advantage of a large coverage area. That coverage comes with a high price tag—the cost of a large number of satellites for persistent offensive and defensive global coverage or a lesser cost associated with fewer satellites and an offensive capability only. Cost is probably the biggest disadvantage to a space-based system—both for an operational capability as well as for its demonstration. In contrast, an airship-based system would be limited to regional coverage, have fewer vehicles deployed, and, according to planners' current estimates, a modest cost for both an operational and demonstration capability.

While support is growing for demonstrating relay mirrors on an HAA, other efforts are also under way. The services recently held a Relay Mirror Workshop at Kirtland AFB and studied ways to develop and demonstrate its technology. The AFRL's Directed Energy Directorate calls its overall relay-mirror paradigm Evolutionary Aerospace Global Laser Engagement, or EAGLE (see fig. 2 and table 1). They have several experiments planned in the near term for potential relay-mirror concepts used in conjunction with ground-based lasers.

While the advantages of a relay-mirror system are many, so are the technical challenges. First, engineers must control the beam characteristics of both the illuminator and the high-energy laser to minimize the size of the mirror that receives the high-power beam. Likewise, engineers must create an uplink capability that can acquire and actively track the location of the relay mirror as well as provide the information required for the adaptive-

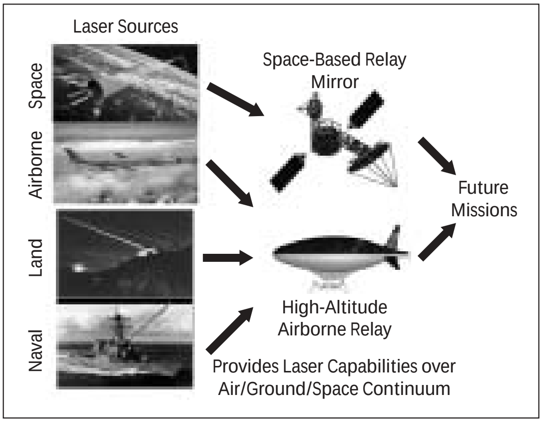

Figure 2. The AFRL EAGLE concept

Table 1. Future missions of a relay-mirror system

Missions
Battlespace preparation
Target designation
Air/ground attack
Space control
- Antisatellite (ASAT)
- Defensive satellite (DSAT)
Asset protection
Cruise missile defense
Ballistic missile defense
- Active tracking
- Discrimination
- Theater missile defense (TMD)

optics feedback loops. Although conventional adaptive optics can accomplish many useful missions, incorporating advanced adaptive optics into the source and relay systems will increase deployment opportunities by maximizing the system's range and efficiency.

Engineers face a different set of technical challenges in developing the relay platform (see fig. 3 and table 2). Despite these significant challenges, relay mirrors are a truly transformational technology for high-energy laser weapons systems.

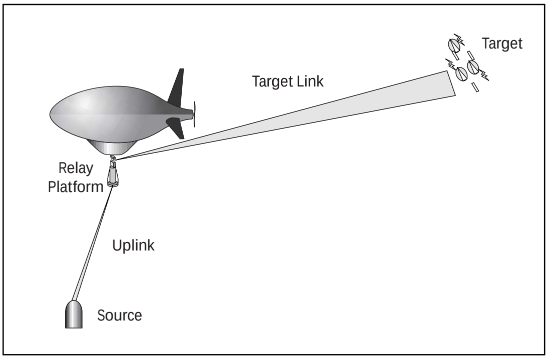

Figure 3. Components of the HAA relay-mirror system

Table 2. Technical challenges of a relay-mirror system

Source
Illuminator characteristics
HEL characteristics
Thermal management
Power and energy

Uplink (source link)
Acquire and actively track relay mirror
Adaptive optics on relay-mirror beacon
Propagate outgoing beam
Advanced adaptive optics
Thermal blooming

Relay platform
Dual line-of-sight stabilization
Acquisition, tracking, and pointing (ATP) in two directions
Boresight alignment and beam cleanup
Rapid retargeting
Separation uplink beams for downlink point-ahead
Lightweight optics
Lightweight illuminator/designator
Internal throughput (coatings, etc.)
Thermal management
Integrated power, energy, and thermal management

Target link
Passive tracking and pointing
Active tracking and pointing
Adaptive optics wave-front sensor (WFS) of target beacon
Aim-point maintenance
Thermal blooming
Tracking through clutter

Target
Active track interactions
Lethality requirements
Target interaction

Relay mirrors not only will enable lethal capabilities, but also will provide numerous opportunities for low-power laser-sensor applications. The 1999 AFRL "Lasers and Space Optical Systems Study" extensively reviewed these applications and concluded that relay mirrors could handle various irradiance, as well as different wavelengths, which could enable a number of long-range sensing applications. The same arguments for achieving system flexibility apply to these applications in the same way as they do for high-power applications.

Conclusions

Clearly there are major milestones, significant challenges, and exciting new technologies facing the high-energy laser community for the next decade or so. High-energy laser weapons research is arguably on the knee of the technological development curve. Weapon-class chemical laser systems—THEL, ATL, and ABL—have demonstrated, or will soon do so, their worth in appropriate environments. The High Energy Laser Joint Technology Office is pushing state-of-the-art, solid-state lasers for tactical applications. Finally, advances in cooperative beacons and advanced adaptive optics are enabling relay-mirror technology to emerge as a significant force enhancer for all high-energy laser systems. These are indeed exciting times, but it is a very tough job and the Air Force cannot expect to be totally successful. Future combat capabilities, as forecasted by these demonstrators and to the degree they are successful, will greatly benefit the US war fighter and provide unprecedented asymmetric war-fighting capabilities for the twenty-first century. □

Niceville, Florida
Kirtland AFB, New Mexico
Maxwell AFB, Alabama

Notes

1. Dio Cassius, *Roman History*, vol. 2, *Fragments of Books 12–35*, trans. Earnest Cary and Herbert B. Foster (Cambridge, MA: Loeb Classical Library, Harvard University Press, 1914).
2. For an excellent account of the historical development of high-energy lasers, see Robert W. Duffner, *Airborne Laser: Bullets of Light* (New York: Plenum Trade, 1997).
3. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century: Directed Energy Volume* (Washington, DC: USAF Scientific Advisory Board, 1995).
4. "Directed Energy Worth Analysis and Vehicle Evaluation (DE-WAVE)," conducted by Lockheed Martin Aeronautics Corporation; "Tactical High Energy Laser Fighter (TAC-HELF) Study," by Boeing Corporation; and "High-Energy Laser Weapons Systems Applications," the Defense Science Board's June 2001 summer study, are three such analyses.

What Should We Bomb?

Axiological Targeting and the Abiding Limits of Airpower Theory

DR. PAUL REXTON KAN*

> *Airpower is an unusually seductive form of military strength because, like modern courtship, it appears to offer gratification without commitment.*
>
> —Eliot A. Cohen

IN THE 100 years since the advent of airpower and its subsequent use in warfare, airmen and strategists still debate the appropriate targets for aerial bombing that will ensure victory. Early airpower advocates promised quick and decisive victory in modern war by selecting and striking targets critical to an enemy's war efforts. They reasoned that by depriving modern nation-states of their ability to use certain key features of their societies, airpower would prevent the horror of trench warfare witnessed in World War I, thereby limiting overall human suffering.

In the post–Cold War era, Western air forces have fought against states led by dictators, ethnonationalist tyrants, and religious fundamentalists; all had little industrial might to sustain open hostilities for a long period of time. Nonetheless, victory came at a substantially lower cost to civilians than was the case during the air campaigns of World War II. The promise of the early airpower advocates seems to have been realized. Although the civilian casualties and significant hardship caused by recent conflict do not match those incurred during World War II, they continue as features of post–Cold War air campaigns.

This article explores a new theory that reopens the debate over airpower's targeting priorities: axiological targeting. Lt Col Peter Wijninga of the Royal Netherlands Air Force and Richard Szafranski first explored this theory in their article "Beyond Utility Targeting: Toward Axiological Air Operations." The term *axiological*, which combines the two Greek words *axios* (worthy) and *logos* (reason or theory), is the study or theory of values—what they are and where they are placed. Wijninga and Szafranski argue that the Air Force should explore axiological targeting as a way of refining the theory and practice of coercive airpower. For them, "the aim of axiological aerospace operations is to use air, space, and information power to force a behavior shift in belligerent leadership in the quickest and most economical ways possible. . . . Value targeting engages the minds and needs of leaders at all levels, knowing that they, and not their war-

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fighting stuff, are the real source of the conflict and its prolongation and the essential ingredient to its resolution."[1] Axiological target sets might include bank accounts and finances, as well as entertainment, sports, and recreational facilities, used by the senior leadership. In other words, axiological targeting sees nonmilitary centers of gravity as more strategic and countervalue targets as more important than counterforce targets.

This new theory seeks to coerce adversaries by holding at risk those things they value most. The authors reason that one can reduce the suffering of innocents even further by striking more personal targets. Unlike previous airpower theories, axiological targeting does not focus on elements that an adversary uses to mount a military campaign. Rather, it is more flexible and more notional in its identification of countervalue targets that may be centers of gravity.

However, this approach is fraught with dangerous assumptions that may put civilians and armed forces at greater risk. In fact, axiological targeting represents the limits of airpower in practice and the complicated logic of airpower as theory. Now that the context of warfare has shifted away from trench fighting of the early twentieth century, one must evaluate how axiological targeting may be applied against today's adversaries on today's battlefields. This article explores the risks of this new theory and demonstrates how it represents the overall limits of airpower in confronting opponents during the early twenty-first century.

What Is Axiological Targeting?

Axiological targeting is part of the school of coercive-airpower thought that believes airpower is uniquely suited to force an adversary to accept the demands of the attacker. It accepts the challenge issued by Robert Pape, who maintains that coercive airpower has significant drawbacks: "The key problem with coercion is the validity of the mechanisms that are supposed to translate particular military effects into political outcomes."[2] Coercion involves the destruction of certain targets but does not require complete annihilation of the adversary or of his necessary means of resistance. As such, axiological targeting becomes a logical extension of the airpower theories of the interwar period. By identifying the correct target set within a center of gravity, airmen can use that set as a lever to modify an enemy's behavior and attitude.

One can easily recognize a campaign of coercion by examining the rhetoric employed by the political leaders of an attacking state—bombing campaigns are designed to "send a message to the leadership" or "ratchet up the pressure" in hopes the adversary will acquiesce to the attacker's demands. The modern airpower of many Western militaries is uniquely suited for a strategy of coercion since adversaries can do little to inflict substantial casualties against air forces that can evade their air defense networks.

The United States Air Force, in particular, can deploy rapidly and bring to bear tremendous and persistent firepower: "The USAF offers a highly versatile coercive instrument. Air power can attack strategic, operational and tactical targets. It can resupply friendly forces and provide essential intelligence. One, some, or all of these functions may play a role in successful coercion."[3] In addition, airpower represents a large part of political calculations that include the quick resolution of a conflict on American terms. One of the advantages the Air Force has over other services is its ability to halt ground invasions or limit aggressions before they become faits accomplis.[4]

Although the Air Force is a potent fighting machine, the challenge of axiological targeting (as with all airpower theory) lies in acquiring the necessary intelligence to glean some insight into the mind of the adversary. How does he meet his particular idiosyncratic needs? What does he value most, and what level of military pressure would make him capitulate? As such, axiological targeting stands in contradistinction to the current theory and practice of utility targeting.

Utility targeting is designed to strike at the means of waging war. Troops, airfields, bases, ships, trains, tanks, aircraft, and command and control (C2) facilities exemplify targets that have a direct use in military campaigns—what Wijninga and Szafranski call "war-fighting stuff." For them, John Warden's five-ring theory is the epitome of utility targeting. According to Warden, one can treat the enemy as a system comprised of five concentric rings (from the inside out): leadership, organic or system essentials, infrastructure, population, and fielded forces. One can target these elements with airpower, either to create a malfunction in the system or induce paralysis, thereby bringing about surrender. Wijninga and Szafranski believe that axiological targeting further refines the center ring of Warden's theory by identifying objects that enemy leaders use to sustain themselves by fulfilling their basic needs.[5]

If Warden's five-ring approach is the epitome of utility targeting in theory, then the epitome of such targeting in practice is the air campaigns of the first and second Gulf wars. Leadership targets were of primary interest to air-campaign planners because by "decapitating" the Iraqi regime, the coalition could prevent Saddam Hussein's military from mounting an effective resistance. In effect, coalition forces paralyzed the regime by targeting enemy leaders, communication systems, and infrastructure in major cities. During Operation Iraqi Freedom, the press referred to targeting by using the terms *shock* and *awe,* which suggested that by conducting precise and simultaneous attacks on utility targets at the initiation of hostilities, the coalition hoped to create so much fear and disarray that the enemy would have little choice other than capitulation.[6] At first glance, hitting Saddam's palaces may seem in line with axiological targeting. However, we considered them utility targets due to the possibility that they contained labs for the production of weapons of mass destruction and/or that they served as fortified bunkers to protect senior Ba'ath Party leaders.

In contrast, the most persuasive case favoring the effectiveness of axiological targeting may be the North Atlantic Treaty Organization's (NATO) air campaign against Yugoslavia in 1999. The goals were purely coercive: "to demonstrate the seriousness of NATO's purpose so that Serbian leaders understand the imperative of reversing course, to deter an even bloodier offensive against innocent civilians in Kosovo, and, if necessary, to seriously damage the Serb military capacity to harm the people of Kosovo."[7] Early on, political leaders selected airpower as the military instrument, excluding any use of NATO ground troops. Debates over centers of gravity and targets soon emerged within the US military and among NATO allies. Although conventional utility targets—fielded forces in Kosovo and C2 nodes—were struck, American air commanders argued for more strategic attacks to break Yugoslav leader Slobodan Milosevic's will. Days of air strikes continued, but the Serbian offensive against the Kosovars intensified, and the humanitarian catastrophe worsened. After much debate and political maneuvering, targets shifted to include institutions that Milosevic used to maintain his rule. As asserted by the Air Force's Lt Gen Michael Short, NATO's joint force air and space component commander, the threat of destroying everything that kept the Serb leadership in power and comfort did the job.[8] Shortly thereafter, Milosevic capitulated to NATO demands.

Axiological targeting has a seductive quality about it—ground forces avoid the harshness of direct conflict, and standoff attacks focus on leadership rather than on civilians. With the advent of greater precision in munitions, targeting has become more accurate, thereby reducing suffering and hardship on both sides of the conflict. However, like the airpower theories before it, axiological targeting is not without its dangers. In fact, these liabilities reveal the genuine limits of airpower in modern conflict.

Influencing Behavior through Bombardment

Much of airpower theory and practice is designed to influence behavior of the adversary. Early airpower theorists concentrated on "civilian morale," believing that a population undergoing sustained bombardment would rise against its government and demand an end to hostilities. At the very least, citizens would be afraid to go to their jobs, thus crippling the target state's economy. Modern airpower thought during and after the first Persian Gulf War focused on paralyzing the leadership or shocking it so completely that it had no choice other than surrender. In this context, morale would mean very little if the adversary were simply incapable of organizing himself to resist.

Axiological targeting represents a return to the belief that airpower can influence behavior. Yet, throughout the history of airpower's use in warfare, human behavior has remained difficult to predict. In many cases, bombing elicited the opposite of the desired response—instead of inciting rebellion, it strengthened enemy resolve; instead of crippling an economy, it led to the streamlining of industry. The case of Kosovo is not clear-cut in terms of illustrating effective airpower coercion or the overall value of axiological targeting. We simply do not know why Milosevic capitulated, but we do know about many other events that occurred during the bombing. For example, the US Army widened roads in Albania, some NATO allies deployed ground troops to Kosovo's borders, and the Russians actively engaged the Serbs diplomatically. Any of these events—or all of them—together with the bombing campaign could have figured into Milosevic's calculations.

Ball-Bearing Factories or Banks?

Although axiological targeting aims for greater precision and the further reduction of civilian casualties, issues of discriminating between combatants and noncombatants remain salient. Although such targeting is designed to inflict more pain on the leadership by striking those things it values, citizens will still suffer. Much like the ball-bearing factories so critical to Nazi Germany's war machine, axiological targets such as banks and sports stadiums are staffed by civilians. Clearly, the targeting of a Serb television station in Belgrade during Operation Allied Force forced war fighters to face concerns about the cost to civilians.

Axiological targeting also fails to heed Pape's advice to study more carefully how state policy can depend upon a single leader. Dictators have proved adept at presenting those things they value as popular symbols of their rule as well as co-opting national treasures as part of their government. If air planners using axiological targeting determine that an ancient bridge is the dictator's most valued item, they cannot dismiss the possibility that the citizenry feels the same way about it. Moreover, knowing that it probably will be bombed, citizens by the hundreds might voluntarily stand on the bridge, hoping to prevent its destruction. Under these circumstances, bombing the bridge would likely fail to conform to the law of armed conflict (LOAC), thereby limiting the flexible application of force that axiological targeting presupposes.

Conversely, if the attacker values something within the target country, such as an ancient temple or museum that contains items of cultural significance, the adversary can position high-value targets and resources nearby in an effort to thwart a bombing campaign. Aerial bombing, no matter the theory, will always be subject to political considerations, moral questioning, and the LOAC. These constraints and strictures do not disappear upon the adoption of axiological targeting and will continue to force airmen into difficult decisions about defining the effectiveness of airpower operations.

Effectiveness of Axiological Targeting

Not an entirely new theory of airpower, axiological targeting instead demonstrates the same shortcomings that have accompanied airpower thought since its inception. Such targeting theory does not solve the puzzle of human behavior, political questions, and moral quandaries. In fact, the most recent example of axiological targeting used by terror groups points to the theory's major drawback.

The attacks by al-Qaeda against the United States on September 11, 2001, prove instructive when one examines the central thesis of axiological targeting. The strikes against the World Trade Center, whose towers symbolized American power and prestige, are a potent example of axiological targeting, but they did not elicit the desired response from the United States. Why, then, should we think that an adversary would act differently if it were subjected to a US axiological-targeting campaign?

The underlying assumptions of axiological targeting continue to be plagued by problems of "mirror imaging"—the notion that Western air forces will confront adversaries who rationally conduct a cost-benefit analysis of their actions. This fallacy further assumes that all enemy leaders value certain things subject to targeting from the air. They may in fact believe it more prestigious to stand up to a bombing campaign conducted by a powerful Western air force. Perhaps the greatest problem of mirror imaging, however, is the belief that Western air forces will inevitably face state actors in the future.

Globalization and Nonstate Actors

Threats beyond those presented by nation-states demonstrate a growing need to understand the role of airpower as an instrument of national power. Axiological targeting still struggles with significant drawbacks when applied to nonstate actors who operate in an increasingly globalizing world. Any new theory of targeting must take into account these actors and the context in which they operate.

Globalization, as described by Malcolm Waters, is a "social process in which the constraints of geography on social and cultural arrangements recede and in which people become increasingly aware that they are receding."[9] This global social process has dispersed information and technology to greater reaches of the planet and, as a result, has empowered various types of human social organizations with the authority to declare war. These groups, such as ethnonationalist zealots, clan-based warlords, terrorist organizations, and even criminal syndicates, now have both the means and the willingness to follow through and wage war, often justifying and employing violence in ways that challenge contemporary understanding of air operations.

Globalization also provides new sources of funding for such groups, permitting them to become more self-sufficient than they were during the Cold War, when the superpowers provided them support. They now take advantage of the transnational nature of globalization by funding their activities through the international trafficking of narcotics, people, small arms, and illegally seized natural resources such as diamonds. Unlike nation-states, these groups do not rely on a national industry, so identifying proper targets for airpower continues to present problems for axiological targeting.

Striking against drug crops or diamond mines valued by a particular nonstate leader still raises issues of behavior modification, morality, and effectiveness when axiological targeting is applied to nation-states. A rebel leader may see his stature elevated merely because the United States or some European country orders an air strike against him. One must also address the problem of discriminating between combatants and noncombatants. Do people who earn a living from drug crops represent legitimate targets? What about those forced to work in diamond mines? Also, regardless of whether one uses utility targeting or axiological targeting in a military campaign against nonstate actors, the LOAC may serve as a hindrance to air-campaign planners and to overall military effectiveness against these types of actors. It is worth exploring whether a conventional counterforce approach would prove more effective.

Evolution of Airpower Thought

Far from fulfilling the promises of early airpower advocates, axiological targeting serves to sustain the conversation about the effectiveness of airpower. If globalization continues to define the context in which challenges to national and international security arise, one would do well to discuss how airpower should be coordinated among various nations and alliances rather than debate what targets to strike from the air. In fact, NATO’s campaign against the Serbs in Kosovo does not illustrate the effectiveness of axiological targeting so much as it demonstrates the need to think of ways to use airpower more effectively in concert with indigenous forces on the ground, such as the Kosovo Liberation Army. After Kosovo, the US airpower operation in Afghanistan also worked closely with another indigenous force on the ground—the Northern Alliance.

Since the end of the Cold War, the United States has used airpower in conjunction with various coalitions and alliances, bringing it to bear against an array of adversaries, from dictators to a radical religious regime. The coordination of these coalitions and the campaigns against these adversaries may foreshadow the challenges presented to us at the beginning of this new millennium. Clearly, further study of how we organize coalitions and how nonstate actors operate would benefit airpower thinkers and leaders. Undoubtedly, however, issues related to morality, effectiveness, and the unpredictability of human behavior will continue to intertwine with future airpower campaigns no matter who participates or against whom we direct them. These basic issues have accompanied advocates of airpower since its advent and application in warfare.

Rather than serving as a point of departure for airpower, axiological targeting asks us to think more creatively about how to meet violent challenges of the near future. The engendering of more discussion on one of the most lethal instruments of power in the world can only help. Thus, axiological targeting remains true to the spirit of early airpower advocates by demonstrating that airpower's use in war continues to be more art than science. □

Maxwell AFB, Alabama

Notes

1. Lt Col Peter W. W. Wijninga and Richard Szafranski, "Beyond Utility Targeting: Toward Axiological Air Operations," *Aerospace Power Journal* 14, no. 4 (Winter 2000): 53, 56, http://www.airpower.maxwell.af.mil/airchronicles/apj/apj00/win00/szafranski.pdf.

2. Robert A. Pape, *Bombing to Win: Air Power and Coercion in War* (Ithaca, NY: Cornell University Press, 1996), 329.

3. Ibid., 5.

4. Daniel L. Byman, Matthew C. Waxman, and Eric Larson, *Air Power as a Coercive Instrument* (Santa Monica, CA: RAND, 1999), 3.

5. Wijninga and Szafranski, "Beyond Utility Targeting," 48.

6. Recent reporting, however, tends to downplay the significance of shock and awe. Gen T. Michael Moseley reveals that less than 10 percent of coalition bombs targeted Iraqi leadership or military command structures. The majority of air attacks went against fielded forces. See *Operation Iraqi Freedom: By the Numbers* (Shaw AFB, SC: Combined Forces Air Component, Assessment and Analysis Division, 2003), 9.

7. Ivo H. Daalder and Michael E. O'Hanlon, *Winning Ugly: NATO's War to Save Kosovo* (Washington, DC: Brookings Institution Press, 2000), 101.

8. John A. Tirpak, "Short's View of the Air Campaign," *Air Force Magazine* 82, no. 9 (September 1999), http://www.afa.org/magazine/sept1999/0999watch.asp.

9. Malcolm Waters, *Globalization* (London: Routledge, 1995), 3.

The importance assigned to air forces by major European powers, among which may be potential enemies, leaves no doubt our future enemies will unquestionably rely greatly, if not primarily, upon the actions of their air forces to bring about defeat of the United States.

—Lt Kenneth Walker

Editor's Note: PIREP *is aviation shorthand for* pilot report. *It's a means for one pilot to pass on current, potentially useful information to other pilots. In the same fashion, we intend to use this department to let readers know about air and space power items of interest.*

Electromagnetic Applications of Biomimetic Research

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FOR THE PAST several years, the Air Force Research Laboratory (AFRL) has been developing sensors capable of detecting electromagnetic radiation across the spectrum—from the infrared (IR), through the visible, and into the ultraviolet regions. These sensors have become integral parts of military weapons systems as well as intelligence, surveillance, and reconnaissance systems—and, undoubtedly, the capabilities we have developed are technologically sophisticated. However, many biological systems possess sensing capabilities unmatched by current technologies. For example, the IR-sensitive beetle (*Melanophila acuminata*) is attracted to fires and smoke 50 kilometers away.[1] These insects are attracted to forest fires because burned trees provide the ideal environment for larvae to develop and hatch into adults. The forest fires emit IR radiation that the beetle detects via a specialized IR sensor known as the IR pit organ or IR sensilla. By understanding the mechanism and the biological processes involved in this IR sensor, one could develop new and improved materials and sensors for Air Force applications.

Literally, the term *biomimetics* means to imitate life. In a more practical sense, biomimetics is an interdisciplinary effort aimed at understanding biological principles and then applying them to improve existing technology. This process can mean changing a design to match a biological pattern or actually using biological materials, such as proteins, to improve performance.[2]

Biomimetics, which had its earliest and strongest footholds in materials science, is rapidly spreading to the arenas of electromagnetic sensors and computer science. This article addresses electromagnetic radiation on either side of the visible, ultraviolet, and IR regions, providing a general overview of recent advancements in biomimetics research as it relates to the Air Force and national defense.

When examining the landscape of biomimetics, one finds the application obvious in a number of areas, many of which are defense related. The study of fish swimming, for

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example, has obvious tie-ins to underwater locomotion and naval interests, and much of the work in structural biomimetics (how biology builds structures) is of interest to the Army due to the potential for producing next-generation, lightweight armor based on naturally occurring biological composite materials.[3] From a commercial standpoint, few biomimetic results have proved as exciting as the recent successes in biologically derived silica and silica polymerization.[4] After all, a significant portion of the economy—especially the technology sector—is based on manipulating silicon. It is easy to understand why the ability to manipulate this element under benign, ambient conditions using biomolecules has many people excited.

Sensing electromagnetic radiation is of particular interest in aviation because of the increasing distances over which sensors need to operate. The ability to detect such radiation in the IR without cryogenics—the science of low-temperature phenomena—has been an important technology driver because of increased sensor reliability and reduced payloads. The latter are becoming even more important as space migration dominates defense and commercial interests. Against this backdrop, it is easy to see why several funding agencies have expanded the area of research in biomimetics—in particular, biomimetic electromagnetic sensing. In short, biomimetics should allow for smaller, lighter, less complicated, and easier-to-maintain sensor systems.

The Materials and Manufacturing Directorate's Critical Research Role

Scientists at the AFRL's Materials and Manufacturing Directorate (ML) at Wright-Patterson AFB, Ohio, working with the Air Force Office of Scientific Research near Washington, DC, and prominent research scientists at universities, have made significant strides in biomimetic research. Their efforts support the Air Force's goal of producing hybrid materials with properties superior to those made entirely of either synthetic or biological alternatives. They also increase our understanding of living creatures that possess unique properties and abilities that we could someday use to enhance the performance and affordability of critical defense technologies.

In fact, biomimetic technologies could have a *profound* impact on materials science and national defense, the principal objective being to use the best biology has to offer to enhance Air Force systems—particularly sensor and detection systems. To achieve this goal, scientists in the directorate's Survivability and Sensor Materials Division (MLP) are drawing upon biology's ability to sense electromagnetic radiation outside the visible-light region. This is important to the Air Force due to the proliferation of and reliance upon sensors and detection systems that operate in the IR region of the electromagnetic spectrum. The quest for understanding this phenomenon has escalated even further as a result of the extreme sensitivity reported in biological IR/thermal detection and because biology, unlike most synthetic systems, can achieve this sensing without cryogenics.

MLP researchers continue to be intrigued by various organisms' ability to sense IR radiation through using the readily available elements of carbon, hydrogen, oxygen, and nitrogen, whereas science's sole option has been a reliance on toxic formulations of inorganic alloys. At various universities around the world, ML supports studies that examine a variety of specimens with unique properties and abilities, including the IR-sensitive beetle; snakes from the boa, python, and pit-viper families; and bacterial-based systems of thermal detection. These investigations have yielded critical insights and have helped ML scientists and others progress toward the development of bio-inspired and bio-derived technologies—the principal research paths in the rapidly growing field of biomimetics.

The resourcefulness of nature in detecting electromagnetic radiation is evident. Less clear is the means of engineering these traits in order to enhance vital technologies and lower their costs. The process of signal processing in biological systems, for example, is very complicated and well beyond the scope of current biomimetics. Instead, researchers are focusing on isolating biological "triggers"—the molecules responsible for initial stimulus detection. They emphasize coupling the triggers into optical and electrical detection systems and bypassing the impossible task of re-creating biological signal transduction. Thus far, in-house researchers have successfully created composite polymer films that electronically report changes in a protein's structure upon IR stimulation. They have also built an imaging array based on this technology, resulting in the world's first biomimetic thermal imager. Current efforts aim to reduce the size and weight of the biomimetic array to allow integration with a Micro-Air Vehicle.

The enormously complex, multistep biological processes associated with biomimetics often operate nonlinearly. In addition, the molecules involved in these processes are sometimes fragile, and integration with other systems can become problematic. Despite these drawbacks, the research holds considerable promise. For instance, biomimetics frequently uses composite materials that provide combinations of properties that no single material can achieve.

Optical Structures

As evidenced through studies of biological visible and ultraviolet systems, nature has evolved incredibly intricate coatings and patterns to reflect, absorb, and transmit light. The complexity of these natural coatings has made replicating them in the laboratory a challenge. For example, many of the curved surfaces involved in fabricating biological coatings would require gray-scale lithography, a sophisticated technique that at present is not considered "standard" in micro- and nanofabrication. Two specific examples include the hawk moth's eye cornea and the beetle's IR sensilla. The 15-micrometer (µm, 10^{-6} meters) domed structures of the beetle IR sensilla are gigantic compared to the feature sizes now produced by the microprocessor industry. Commercial companies are currently engaged in applying advanced lithographic procedures to replicate biological surfaces, and many of these techniques are being applied to nonstandard (i.e., nonsilicon) materials like germanium.

Believing that replicating the surface structure of a snake's IR pit organs would constitute a significant advancement in optical coatings for IR optics, ML scientists involved in biomimetic research have given top priority to this endeavor. The micropits of the IR pit organ, for example, are approximately 300 nanometers (10^{-9} meters) in diameter, and the scale ridges are spaced at 3.5 µm. The latter dimension has implications for the IR spectrum, and the former has visible-light consequences. In recent publications, ML researchers have reported successful holographic duplication of snake-scale structure in a photopolymer matrix.[5] A holographic approach uses light to record the fine details of a biological surface. By combining this "reading" beam and a reference beam, one produces an interference pattern that can record a multitude of biological information. Advances in materials-fabrication techniques and optical coatings currently under way have the potential to improve the performance of virtually every military optical system that exists.

Thermal and Photon (Quantum) Detectors

Before proceeding from coatings to the application of biomimetics to IR sensors, one would do well to review the state of artificial or man-made sensors. Broadly speaking, IR sensors fall into two categories: thermal detectors and photon—or quantum—detectors. On the thermal side are thermocouples, thermopiles, bolometers, and pneumatic (Golay) detectors. For example, the microbolometer format for thermal imagers currently dominates this class of state-of-the-art, noncooled IR detectors for applications in US Army thermal-imaging systems, civilian firefighting applications, and even Cadillac's night-vision systems for automobiles. On the photon-detector side are photoconductive, photovoltaic, and electromagnetic detectors. In general, this class of detectors—commonly used for space applications—is made from semiconductor materials and must be cryogenically cooled. The response time of the detector and the speed of the potential target have always constituted the principal difference between these two categories. Thermal detectors respond relatively slowly (on the order of milliseconds: 10^{-3} seconds) compared to photon detectors (on the order of microseconds: 10^{-6} seconds).

Researchers have concluded that biological IR sensing is a thermal process, but how then does one apply this knowledge to new detector strategies? To compete with an artificial, inorganic detector that directly converts a photon to an electron, one needs to make the biological thermal process more efficient. In a biological system, IR photons are absorbed into the system via molecular resonant frequencies inherent in the chemical structure of the tissue. In essence, this energy transfer from the IR photons causes the molecules within the system to "vibrate" on the molecular level. This molecular motion eventually dissipates as thermal energy on a very minute scale. Researchers at ML believe that the thermal change is sufficient to trigger a signal in the terminal nerve masses of the IR pit organ that eventually leads to a change in the neuron firing rate to the brain, which in turn interprets this change as either "hot" (increased rate) or "cold" (decreased rate). A successful biomimetic approach would simplify this process by engineering the "trigger" in this process—the original IR-absorbing biological macromolecule.

Bacterial thermoproteins provide a model for this engineering process since they have the ability to manipulate bacterial genes easily and produce the desired recombinant proteins via fermentation. To increase the efficiency of this biological system, ML researchers are exploring ways of optically sensing thermally induced changes in protein structure. One common laboratory technique—the use of circularly polarized light in circular dichroic (CD) spectroscopy—optically records changes in protein secondary structure to study the dynamics within the biological system. A recent publication addressed temperature-induced changes in polymer-hydrogel swelling behavior using synthetic coiled-coil domains and CD spectroscopy to examine the dynamic range and elasticity of the structure.[6] ML researchers are examining similar sensing concepts (fig. 1).[7] A critical step in the maturation of biomimetics for electromagnetic sensing will entail meshing traditional synthetic polymer synthesis and processing with biochemistry and molecular biology and then successfully applying "soft-matter" lithography. This approach of combining biological macromolecules with synthetic polymers is key to maintaining the functionality of the biological element, while imparting an appropriate avenue of signal transduction and / or propagation.

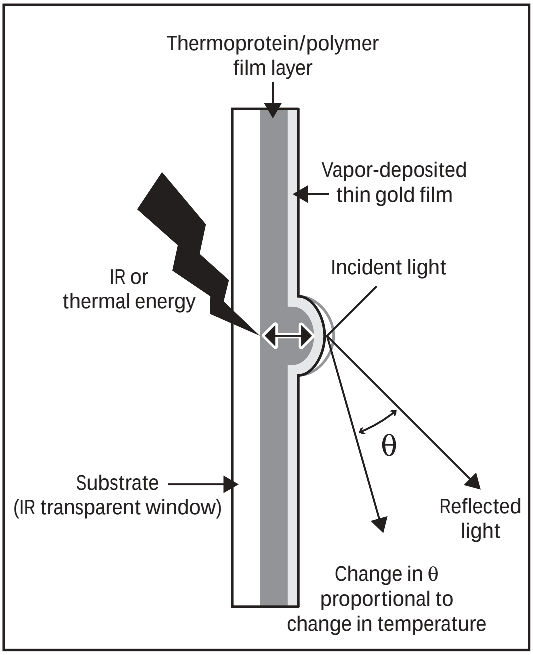

Figure 1. Schematic drawing of a thermal sensor based on a thermoprotein. (Reprinted from Morley O. Stone and Rajesh R. Naik, "Applications: Biomimetic Electromagnetic Devices," in *Encyclopedia of Smart Materials*, ed. J. A. Harvey [New York: John Wiley & Sons, Inc., 2000], 112–21.)

Conclusion

There is a growing awareness of the contribution that biomimetics can make to numerous well-established research areas, of which electromagnetic sensing is a small part. The highly interdisciplinary nature of biomimetic work makes it difficult for a single research group to be successful unless its expertise truly spans multiple scientific disciplines. Additionally, few areas span basic, fundamental science to applied research as completely as biomimetics. Bearing this grand challenge in mind, one remains cognizant of still-undreamt advances that can occur by imitating nature's optimization, which has occurred across millions of years. Continued research in biomimetics by the Air Force could lead to the development of dynamic materials, devices, and processes that directly support the war fighter by heightening the performance of vitally important military technologies and by reducing costs. These advances in the understanding of the natural world benefit science at large and provide opportunities for innovative commercial applications never before possible. □

Notes

1. Wulfila Gronenberg and Helmut Schmitz, "Afferent Projections of Infrared-Sensitive Sensilla in the Beetle Melanophila Acuminata (Coleoptera: Buprestidae)," *Cell Tissue Research* 297, no. 2 (July 1999): 311–18.

2. Charles S. Zuker, "The Biology of Vision in *Drosophila* (G Protein / Phospholipase C / Ion Channels / Signal Transduction)," *Proceedings of the National Academy of Science, USA* 93 (1999): 571–76.

3. Michael Sfakiotakis, David M. Lane, and J. Bruce C. Davies, "Review of Fish Swimming Modes for Aquatic Locomotion," *IEEE Journal of Oceanic Engineering* 24, no. 2 (April 1999): 237–52; X. Shen et al., "Molecular Cloning and Characterization of Lustrum A, a Matrix Protein from Shell and Pearl Naore of Maliotis Rufescens," *Journal of Biological Chemistry* 272, no. 15 (December 1997): 32472–81; and Mehmet Sarikaya, "An Introduction to Biomimetics: A Structural Viewpoint," *Microscopy Research and Technique* 27 (1994): 360–75.

4. Nils Kröger, Ranier Deutzmann, and Manfred Sumper, "Polycationic Peptides from Diatom Biosilica That Direct Silica Nanosphere Formation," *Science* 286 (November 5, 1999): 1129–32; Jennifer N. Cha et al., "Silicatein Filaments and Subunits from a Marine Sponge Direct the Polymerization of Silica and Silicones *in Vitro*," *Proceedings of the National Academy of Science, USA* 96, no. 2 (1999): 361–65; Rajesh R. Naik et al., "Silica-Precipitating Peptides Isolated from a Combinatorial Phage Display Peptide Library," *Journal of Nanoscience and Nanotechnology* 2, no. 1 (2002): 95–100; and Rajesh R. Naik et al., "Controlled Formation of Biosilica Structures in Vitro," *Chemical Communications* 2 (2003): 238–39.

5. Sean M. Kirkpatrick et al., "Holographic Recording Using Two-Photon-Induced Polymerization," *Applied Physics A* 69 (2002): 461–64; and Morley O. Stone et al., "Ultrafast Holographic Recording of Snake Infrared Pit Tissue Using Two-Photon Induced Photopolymerization," *Photonics West, SPIE Proceedings* 36 (2000): 3934.

6. Chun Wang, Russell J. Stewart, and Jindrich Kopecek, "Hybrid Hydrogels Assembled from Synthetic Polymers and Coiled-Coil Protein Domains," *Nature* 397, no. 6718 (February 1999): 417–20.

7. Rajesh R. Naik, Sean M. Kirkpatrick, and Morley O. Stone, "The Thermostability of an Alpha-Helical Coiled-Coil Protein and Its Potential Use in Sensor Applications," *Biosensors and Bioelectronics* 16 (2001): 1051–57.

Centralized Control

It is crucial that one commander have the authority and responsibility for planning, coordinating, and executing joint air operations. According to Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine*, *centralized control* is "the planning, direction, prioritization, synchronization, integration, and deconfliction of air and space capabilities to achieve the objectives of the joint force commander" (p. 34). The concept of centralized control—an airman centrally controlling all theater air and space forces—is often referred to as the *master tenet* and must be adhered to if the joint force commander is to receive those forces' maximum combat capability.

As with all the tenets of air and space power (*decentralized execution, flexibility and versatility, synergistic effects, persistence, concentration, priority, and balance*), centralized control requires an airman to have the necessary insights and understanding, keep things in their proper perspective, and provide appropriate direction to the integrated joint air and space forces. Successful commanders will remember that all wars are unique and provide important lessons, but the next war will always be different. The airman in charge of the current war must always draw on history, analyze his (or her) and others' recent experiences, and then adjust and apply doctrine to achieve the greatest results with the joint forces with which he (or she) has been entrusted.

Working hand in hand with decentralized execution, an airman must implement centralized control of air and space forces, maintaining a strategic perspective of the big picture to prioritize and balance the limited resources at his or her disposal. That airman, the *joint force air and space component commander* (JFACC), is the single focal point for employing a joint commander's air and space forces and is best positioned to ensure that each demand is heard and that the competing demands are appropriately prioritized. That requires the JFACC to develop and maintain a handle on theaterwide operations.

The doctrine of centralized control has been violated at various times in history with predictable results. The competition for air assets in North Africa at the beginning of World War II and again during most of the war in Southeast Asia was intense, causing airpower capabilities to be fragmented and placed under the control of various lower-level commanders. Without having a single airman in charge, scarce resources were not properly prioritized and were, therefore, often misallocated, causing delays in achieving operational objectives. The lessons learned in North Africa became part of the Army Air Corps's doctrine, documented in the War Department Field Manual 100-20, *Command and Employment of Air Power,* dated July 21, 1943:

> The inherent flexibility of air power, is its greatest asset. This flexibility makes it possible to employ the whole weight of the available air power against selected areas in turn; such concentrated use of the air striking force is a battle winning factor of the first importance. Control of available air power must be centralized and command must be exercised through the air force commander if this inherent flexibility and ability to deliver a decisive blow are to be fully exploited. Therefore, the command of air and ground forces in a theater of operations will be vested in the superior commander charged with the actual conduct of operations in the theater, who will exercise command of air forces through the air force commander and command of ground forces through the ground force commander.

This War Department manual well explained the need to have an airman in control of theaterwide airpower (and now space-power) resources—the beginning of the centralized-control concept. The lessons learned during Vietnam only serve to reinforce that earlier doctrine as the most effective way to employ air and space forces.

To Learn More . . .

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine,* November 17, 2003. https://www.doctrine.af.mil/Library/Doctrine/afdd1.pdf.

Fawcett, Lt Col John M., Jr. "The JFACC Team." *Air & Space Power Chronicles*. http://www.airpower.maxwell.af.mil/airchronicles/cc/fawcett.html.

Polowitzer, Maj William G. "Role of the JFACC in Future Conflicts." Alexandria, VA: GlobalSecurity.org, 1993. http://www.globalsecurity.org/military/library/report/1993/PWG.htm.

Getting There FIRST

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Editorial Abstract: The US Air Force's broad-based research and development program allows it to remain preeminent in the creation of new technologies. A strong and rapid product-development capability turns these technologies into fieldable systems, and a robust production capacity efficiently produces the number of weapons it needs at an affordable price. All of these elements require a way of thinking about large organizations and technical innovation that involves flexibility, innovation, resources, support, and tempo (FIRST).

IN MILITARY COMBAT, firing the first shot is often critical to victory; being first is also important in innovation and technology. For example, Elisha Gray, a very successful and wealthy American inventor, is barely known today because he found himself at the patent office just a few hours behind a competing inventor—Alexander Graham Bell, who had also come up with the idea for the telephone. Although one might reasonably argue that the telephone was simultaneously invented by several different groups (including three competitors outside the United States), Bell had a design that could be easily reproduced, and he enjoyed the industrial advantages of the United States—not to mention the fact that he was first in line at the patent office. Patent rights do not usually protect military technology, but those who are first to employ a new war-fighting technology often gain the advantage. Being the first to develop the atomic bomb gave the United States the leverage to conclude World War II and dictate the terms of peace. The same principle holds true with regard to the impact of stealth technologies or precision weapons guided by the global positioning system (GPS) on our current military advantage. In virtually all competitive situations, being first forces opponents to react to actions; it also sets standards and allows the initiator to shape the direction of other development efforts.

How does the US Air Force assure itself of first place in terms of having the most significant military technologies? The service relies on a broad-based research and development

(R&D) program for new technologies, a strong and rapid product-development capability to turn these technologies into fieldable systems, and a robust production capacity to efficiently produce the number of weapons it needs at a price it can afford. Because all of these elements require innovation, this article addresses the R&D effort and the science and technology (S&T) that comprise the seed corn for future capabilities.

Current State of Research and Development

Contributing in R&D doesn't necessarily mean being the first to do the whole thing, but it clearly means being first at something. This goal is easy to understand for individuals and small teams. What, however, does one do with large organizations that also need to be innovative?

Like most industrial nations, the United States provides for R&D through a "three-legged stool." The best known leg is academic research institutions. Although founded for the purpose of learning, these organizations represent the oldest, most evolved research structures available and provide the greatest results in terms of fundamental science. The other two legs—commercial industry and government research organizations—play key roles in turning the seeds of science into producible, deployable fruits. Typically large laboratories and development centers, they are capable of conducting activities on a wide scale—from short-term studies by individual researchers to massive, highly collaborative national-level efforts. Such organizations include Bell Labs, Palo Alto Research Center (PARC), Sandia National Laboratories, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and the Air Force Research Laboratory (AFRL).

Over the past decade, these organizations have experienced considerable decline; indeed, many people now question their relevance. Some see these organizations as overgrown bureaucracies more interested in the preservation of budgets and empires than in the conduct of new research or the delivery of new technologies.[1] Others argue that because the technology base has changed, these large organizations have no role because we don't need new rockets, hypersonic vehicles, nuclear weapons, and so forth. Still others point out that the commercial-electronics and computer-software industries remain our only meaningful source of innovation. One must also consider the assertion that so much technology is up for grabs that organizations no longer need to invest in R&D themselves—they can just pick from the tree of knowledge (from others' research) for free. Thus, AT&T divested itself from most of Bell Labs, Xerox got rid of PARC, and most *Fortune* 500 companies have downsized their central R&D efforts.[2] Are these research organizations truly dinosaurs of another technology and business era? Although some of these arguments may have merit, the fact remains that the world is becoming more technologically sophisticated, not less. Nations (or companies) that ignore the need to stay in the forefront of R&D do so at their own peril.

If there is a grain of truth to these complaints about large R&D organizations, what can the Air Force do? To some degree, the answer lies in understanding the nature of the "new" economy and the qualitative change in business philosophy from monolithic entities to supply chains. For most of the twentieth century, an automotive manufacturer, for example, made nearly all of the components for its automobiles. Different divisions made engines, exhaust systems, bodies, interiors, and so forth. Although a few external businesses such as Bendix and Delco supplied brakes, starters, and batteries, the monolithic entity often purchased and absorbed these companies. Economies of scale dictated that the manufacturer control as much of the process as possible in order to regulate volume, quality, efficiency, and rhythm. This trend changed in the last part of the twentieth century as manufacturing techniques improved and the information age began. Companies can now outsource significant pieces of their business yet specify quality and track inventories well enough to realize a different economy of scale that uses the entire external economy, minimum capital investment, and maximum agility. In many cases, these supply chains are managed several layers deep. In other words, an automaker now outsources most parts, often dictating the sources of their suppliers' raw material and tracking their quality and inventories as well. How is this new economy relevant to R&D? Essentially, the R&D community uses supply chains too.

One might argue, however, that R&D has always been managed by supply chain. From the beginning of scientific discovery, the work of one researcher led to insight and publication by another, and so on; thus, ideas grew as they circulated, and researchers used the worldwide knowledge base available through publication. Today, many organizations have tried to exploit the new economy more explicitly by increasingly outsourcing R&D, either by hiring others to do it for them or by not doing it at all and thereby counting on the technology base to provide all their needs without charge. Both of these approaches suffer from pitfalls. Outsourcing R&D may lead to research results, but organizations that have no role in their discovery often find these results difficult to exploit. Those who decide not to engage in R&D find themselves at the mercy of the marketplace and in terrible danger of rendering their work late, obsolete, or—even worse—irrelevant.

New Approach to Research and Development: FIRST

A more sensible approach entails examining what makes the new economy tick—agility. Supply-chain systems allow small entrepreneurial teams to exploit the work of other small teams. Sometimes those teams are located outside the parent organization; sometimes they are within. Small teams can change. They can drop one path and pursue another, change their entire business, or disband, thus allowing their members to form again into new teams. But large, monolithic organizations have a difficult time with agility, a situation which produces the great R&D quandary of the twenty-first century: we often need large R&D efforts, yet we want these organizations to be entrepreneurial and take advantage of changes in the economic system. How do we do it? By getting there first and by getting there with a way of thinking about large organizations and technical innovation that involves *f*lexibility, *i*nnovation, *r*esources, *s*upport, and *t*empo (FIRST):

- *F*lexibility: Organizations must establish themselves so that they either adapt to their environment or influence that environment to make the most of their opportunities. The key to flexibility is encouraging the dynamics of small teams and eliminating "borders."
- *I*nnovation: Organizations must foster new approaches, not stifle them. The key to innovation is setting aside resources for fresh opportunities and identifying and killing fruitless efforts.
- *R*esources: Organizations must provide substantial financing. The key to resources is providing funding that is generous, realistic, stable, and sufficient for all efforts.
- *S*upport: Organizations must build up their scientific and engineering (S&E) workforce, giving it a role in their future and leadership. The key to support is focusing on the skill growth of the R&D cadre.
- *T*empo: Organizations must understand the importance of managing time, both in terms of long-term vision and of pursuing opportunities rapidly. The key to tempo is realizing that in many cases, time is probably more valuable than money and must be treated as such.

We now address how one can apply the FIRST principle to a large research organization such as the AFRL. Although the remainder of the article examines the AFRL in particular and the Air Force and Department of Defense (DOD) R&D systems more generally, the issues of adapting to the new economy are by no means unique to the Air Force. That said, it is critical that our service maintain technological superiority over any potential adversary. As part of the DOD transformation effort, the Air Force is undergoing considerable introspection to examine its role and ways of doing business. Against this backdrop, the service has a healthy perspective on prospective changes and improvements.

With over 5,000 people, installations throughout the United States, and 10 substantial research directorates covering a wide variety of disciplines (sensors, propulsion, information systems, air vehicles, human factors, munitions, materials, directed energy, space, and basic research), the AFRL is a good example of the large government establishments alluded to earlier. Although the AFRL itself is technically less than 10 years old, its components have rich histories over the past 30–60 years. During that time, these organizations have made numerous critical contributions to the national military-research effort, including key roles in integrated-circuit development, jet propulsion, adaptive optics, directed energy, phased-array radar, error detection/correction coding—far too many to list here. In most cases, the AFRL plays the role of integrator of ideas and source of funding, letting external laboratories conduct the actual research. Today, most such efforts come together in procedures developed well in advance through extensive strategic planning. Although the AFRL's results are unquestionably impressive, FIRST principles involve asking how one can make the system better and more competitive with other research establishments.

Flexibility

To be flexible is to make the most of opportunities, wherever and whenever they arise. Simply changing organization charts, mission statements, and the like does not necessarily reflect flexibility. Rather, flexible organizations tend to focus themselves more on overall contribution than on parochial roles and ways of obtaining results. Perhaps one of the best stories of organizational flexibility is the 3M Corporation's development of the Post-it Note. The company encouraged extramural R&D from its staff and allowed itself to capitalize upon the results. The Post-it emerged as an innovation from an adhesives-group effort that fell outside normal group objectives, but senior management decided to attempt pilot production rather than quash the effort, resulting in over $200 million in sales within the first couple of years.[3]

The opposite of flexibility is not a fixed organizational structure but boundaries that limit the cross-fertilization of ideas. Organizations can take a very rigid view of their mission and role, often as the result of negotiations with competitors or the desire to reduce duplication of effort. Thus, for example, the electronics laboratory agrees to have nothing to do with propulsion, and the Air Force agrees to have no involvement in ground vehicles. The problem is that research is shaped by the creativity of the workforce and is seldom planned. Bell was a speech therapist—not an engineer—but his background proved to be exactly what he needed to develop the telephone. The Wright brothers were bicycle makers—not aeronautical engineers—but their background in machining proved critical, matching well with their extensive self-study of aerodynamics. Similarly, the modern study of neural networks in artificial intelligence is the result of psychologists dabbling in computer science.[4] One might argue that the most fruitful science doesn't happen within disciplines as much as it does along the permeable boundaries between them. Establishing roles eliminates these productive boundaries. At first, however, this concept seems counterintuitive. On the surface, it seems sensible that forcing researchers to focus on the tasks clearly delineated in their organization's mission would lead to better results. But human creativity doesn't work that way. Cross-fertilization is really the key to success, and goals have to be interpreted a little more loosely in research because it is a business full of surprises.

Judged against this view of flexibility, the government gets mixed reviews. On the one hand, most government organizations encourage collaboration among their own components and with outside entities. Programs like Dual Use Science and Technology, for example, team multiple government labs with industry in collaborative efforts. The Multidisciplinary University Research Initiatives program provides government funds to universities for building winning proposals from multiple research departments to promote interdisciplinary efforts. Interdisciplinary, interorganizational work is very good but still falls short of the kind of flexibility shown by 3M in its Post-it story. What happens when someone in the electronics lab comes up with a design for a new engine? According to the current government procedure, the electronics lab can work with the propulsion lab, but the latter agrees to do only the propulsion part and the former to do only the electronics part. So what happens to the new-engine idea? Normally it dies because it did not originate in the propulsion lab, which, therefore, isn't particularly interested. To keep the idea alive, the electronics lab should allow its own employees to pursue the concept at least far enough to develop sufficient interest externally. If the idea is really good, the electronics lab will spend some of its own resources and encourage the inventor to build a team of "disciples," at least until they can expand upon, prove, and even market the idea.

Unfortunately, like most large organizations, the government does the opposite. Take, for example, the Defense Reliance program, created in the early 1990s as the result of pressures from Congress and the Pentagon to eliminate wasteful duplication in research. Each service laboratory agreed to pick nonoverlapping specialties and to avoid research in areas that invade each other's turf. Thus, the Air Force does fixed-wing aerodynamics, and the Army does rotary-wing. Furthermore, the Army does unmanned ground vehicles, the Air Force does unmanned (fixed-wing) air vehicles, and the Navy does unmanned undersea vehicles (despite the fact that these three types of vehicles share many common research issues and often need to play together in creative architectures).

People also tend to evaluate flexibility by looking at the organization chart, the idea being that an organization is flexible if it can change its management structure from time to time. Indeed, organizational change can imply adaptation to pursue opportunity. Often, however, it reflects such internal issues as the advancement of careers and the protection of budgets. Frequently, ordinary workers notice no significant change in their environment as a result of major organizational restructuring.

The kind of flexibility described here does not really pose a threat to organizational cohesion and identity. Organizations normally maintain their character by means of mission statements, image, and hiring decisions. People also have a natural tendency to organize themselves around themes and to seek out organizations with the appropriate "labels." The psychology departments at Stanford and the University of California–San Diego remained psychology departments in spite of the fact that their professors and students dabbled in computer science and neural networks. The point is that flexibility remains possible within large organizations that choose to seize opportunities.

Innovation

Discretionary funds must be made available for new initiatives and innovation, for innovation and venture capital are very closely related. Moreover, research staffs should be able to move on to something new upon completion of a project, successful or not. Funds profitable prededicated through strategic plans do little to help the kind of project-to-project mobility so critical to innovation. Similarly, external direction from Congress, the Office of the Secretary of Defense (OSD), or the Air Staff may be important in some cases for particular programs, but in general, such direction can easily hinder innovation. The Air Force's doctrinal tenet of centralized control and decentralized execution serves as a sound guiding principle in R&D situations as well. Leadership can establish a standardized process for starting new efforts and killing old ones (the centralized-control aspect) while scientists and engineers propose, develop, and pursue new technology opportunities (decentralized execution). The ability to terminate unproductive programs and mitigate overhead costs is of key importance because such innovation requires discretionary funding. One of the most effective ways of ending programs occurs through an initiative process.

For many years the Air Force Office of Scientific Research, the service's basic research-management organization, cultivated an active initiative program. Each fall, senior leadership voted to terminate a percentage of ongoing programs that had concluded successfully, failed to produce the desired results, gone on too long, or become insignificant players. Money from terminated programs went into an initiative account. In order to counter the temptation of not terminating enough programs, the initiative account was balanced by "taxing" ongoing programs. Thus, the leadership could either terminate something or pay a high tax. Every spring a competition was held to select initiatives from creative ideas proposed by staff members. Unfortunately, this system no longer exists, replaced in the early 1990s by a multiyear, top-down strategic plan with the glorious title "New World Vistas."

Innovation capital is essential not only because it provides funding for new ideas, but also because it promotes the kind of internal personnel mobility and organizational flexibility so critical to agility. Without flexible funding, R&D staffs are loathe to terminate existing programs because they know that new funding will be hard to come by. Insufficient funding, in turn, will have a detrimental effect on their job environment, satisfaction, and success. Long-term strategic planning is a poor substitute for initiative capital because it replaces short-term creativity with a road map that often takes too long to implement.

Resources

Several kinds of resources or capital are key ingredients to successful R&D: money (certainly the most visible and tracked item), people (discussed in detail under "Support," below), and facilities. Finally, location is often an overlooked asset (or liability) that has much to do with the productivity of a laboratory; thus, laboratories located in Boston or Palo Alto may enjoy much higher success than those in the middle of Iowa.

Since the extensiveness of the facilities and the number and quality of the people are closely tied to money, funding deserves the kind of attention that one might expect. Although the bottom line remains the most visible issue in funding, other issues may be just as important. For example, can funds be applied easily in a timely manner? Building a system around strategic planning such as the government's Planning, Programming, and Budgeting System (PPBS) may require long delays and intensive manpower just to advocate, track, and disburse money, therefore negating many of the potential benefits of having funds in the first place. Thus, funding methods must match the organization's view of how it will address flexibility, innovation, and project tempo.

In many cases, however, adequate funds simply are not provided, or they lack the necessary stability to fully enable the R&D enterprise. Although Air Force labs are well funded by outside-observer standards, the long-term trend generally has not been promising, and one might also argue that the budget is not very stable. Air Force S&T funding dropped precipitously after the late 1980s to less than that for both the Army and Navy in 1993 and 1998, respectively (figs. 1 and 2).[5]

The question certainly arises as to why these reductions have been made. Is Congress or the OSD forcing these changes? One can trace the relative adjustments made to the Air Force's S&T budgets for fiscal years 2000 (FY00), FY01, and FY02 during the PPBS process from 1997 through 2002 (fig. 3). Numerous adjustments were made to the S&T budget throughout the Future Years Defense Plan; however, in most cases the adjustments decreased the S&T budget, pointing both to a potential lack of sponsorship within the Air Force and a pen-

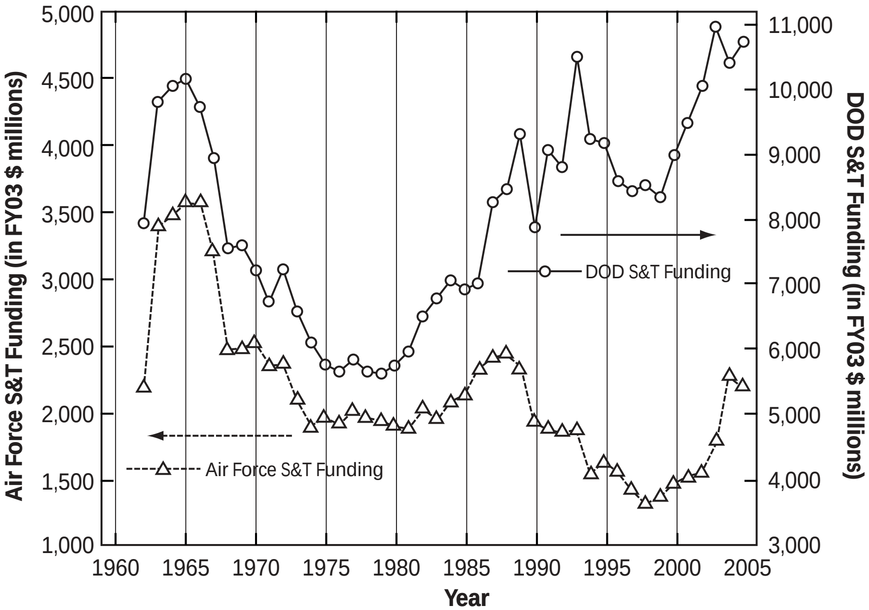


Figure 1. Air Force and DOD S&T funding. (Data from *FY 2004 Defense Budget* [Washington, DC: Office of the Undersecretary of Defense (Comptroller), February 2003].)

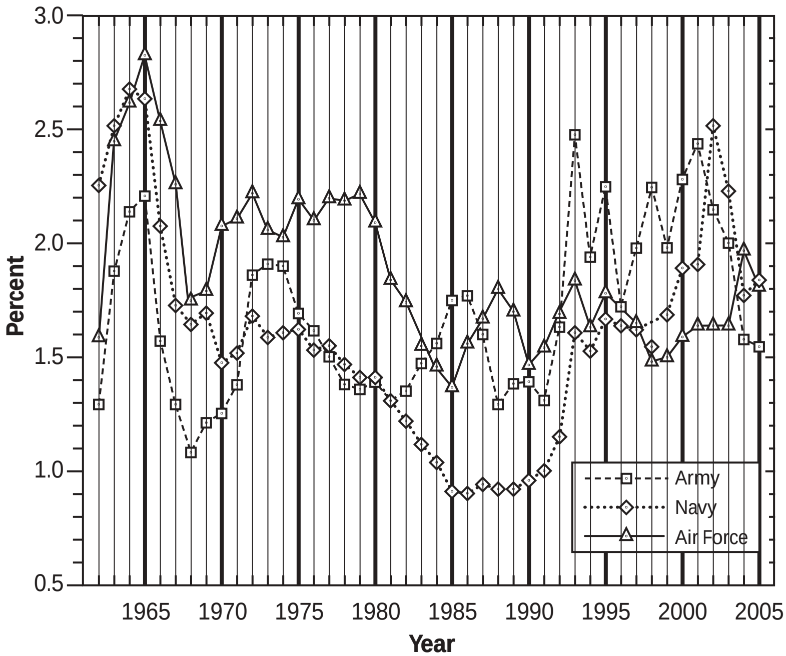


Figure 2. S&T funding as a percent of service total obligation authority. (Data from *FY 2004 Defense Budget* [Washington, DC: Office of the Undersecretary of Defense (Comptroller), February 2003].)

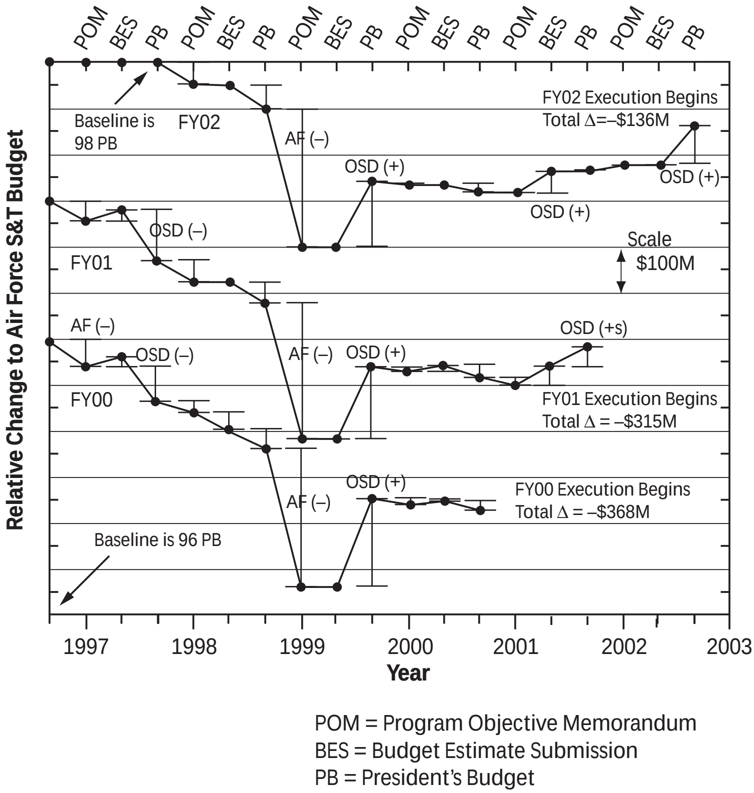


Figure 3. FY00, FY01, and FY02 Air Force S&T budget decisions through the FY97–02 PPBS cycle. (Adapted from briefing, Roy Phillips, to James Engle (SAF/AQR), subject: Air Force S&T Funding Analysis/Discussion, June 18, 2002.)

chant for using S&T as a funding source for other Air Force priorities. Interestingly, the Air Force was responsible for 78 percent of the decreases in S&T funding while the OSD accounted for 98 percent of the increases over this time period. Although falling far short of restoring the cuts, the OSD has generally countermanded the Air Force's S&T cuts. The Air Force might have many reasons for using the S&T budget as a bill payer, but such cuts do not provide the stability that promotes the kind of innovative organization mentioned above.

In addition to reducing funding, Congress has become increasingly involved in the Air Force's S&T program decisions. According to the AFRL, the magnitude of this oversight has grown from zero in FY95 to approximately 14 percent of the AFRL's budget in FY02 (fig. 4). Congressionally directed research may yield useful innovations for the Air Force, but it greatly reduces the discretionary funding so critical to innovation.

Normally, most organizations have basic infrastructure requirements that create bills which must be paid, regardless of the audacity and vision of their leaders. Likewise, they have ongoing commitments that establish must-pay bills. Unstable and declining budgets present serious difficulties for an R&D organization because they tend to remove critical discretionary funds first. Thus, small start-up teams are far more likely to lose funding, even though such teams often represent the greatest opportunities for innovation. Does

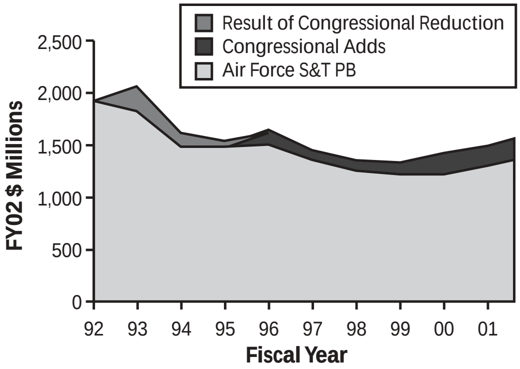


Figure 4. Evolution of congressionally directed research

this mean that a research organization cannot downsize and still remain productive? Not at all. What matters is that such an organization preserve enough stability to know how to size itself as time progresses so it can maintain a stable discretionary budget.

Support

One must support the S&E workforce in order to have agility. Workers need an environment in which they can experiment, form and dissolve teams as needed, and associate with peers who push them toward excellence. Finally, they need to feel content enough about their work that they choose to come and stay.

Unfortunately, the military finds itself at a considerable disadvantage in this arena, having already experienced a significant dismantling of its S&E workforce. For example, although the Air Force's program offices have retained more or less the same organizational structure for the past three decades, the S&E portion of military officers diminished from 56 percent in 1974 to 14 percent in 2001.[6] (Specialization is categorized in terms of the highest degree held in a technical specialty.) Furthermore, the story may be even worse than these dire numbers suggest. Many S&E personnel report that their work often has little or no technical content, that most of this work is surrendered to contractors, and that they are not really used even though they are needed.[7]

The Air Force must make a substantial effort to rebuild this workforce; indeed, certain key reforms have already begun. Of all the areas discussed thus far, the service is likely treating support of the S&E workforce most seriously. For the past three years, it has held two senior-level S&E summits, published an S&E concept of operations, expanded graduate-education programs, made certain changes in hiring and assignment policy, and enacted special-pay incentives (although some of these pay incentives have now been cancelled). All of these modifications appear to have enjoyed some success, but they have not completely turned the corner in terms of improving the quality and quantity of the S&E workforce. Evidently, these changes do not directly address the top issue raised in survey groups—the desire for more meaningful and challenging work. Such qualitative changes in working conditions are vital not only to enhancing job satisfaction, but also to running an agile R&D program. Thus, the improvement of technical content is a win-win proposition.

Perhaps of most critical importance, the Air Force must completely settle the issue of how it should best use its S&E workforce. Today, one encounters many competing visions of the role of government in R&D, most of which are incompatible. For example, hiring engineers in order to build a strong internal R&D capability is fruitless if they are used merely as contract monitors. The Air Force must take steps to end the instability in roles-and-management practices with which its S&E workforce has coped over the years. Stability depends in large part upon making other reforms that will exploit this workforce to the fullest.

In short, much is being done to support the S&E worker in the Air Force and, thus, within the AFRL. However, because all of the FIRST factors interlock, without the right organization, philosophy, budget, vision, and so forth, the workforce may flounder. Such a prospect underscores the urgency of dealing with the other topics at hand.

Tempo

One could argue that in America we do things on "too" time scales: too short and too long. Too short because we don't have the patience to run investments past an immediately foreseeable payoff; thus, we miss contributions of great value. Too long because we actually believe that our detailed strategic plans will not be overrun by events. Ideally, we would replace them with "to" time scales: *to*ward a meaningful, long-term vision and *to*ward faster results on a project scale. In other words, we could replace detailed strategic plans with visions such as "we expect to have an entire unmanned strike force" or, as President Kennedy proposed in 1961, "to land a man on the moon before the decade is out." Such visions are quite different from the detailed, committee-built road maps (strategic plans) that list endless series of projects, each funded according to the political winners or losers of a given year. On the other end of the scale, we need to ensure that we pursue ongoing projects with a sense of urgency seldom seen in government. Doing so may entail initiating fewer projects, finishing them, and then turning resources toward other promising activities.

The benefit of a new technology to the military depends upon the advantage it provides multiplied by the time the system operates before a countersystem negates it, or multiplied by the total amount of time a cost-saving technology is deployed. In either case, the time to develop and field that technology directly affects its overall value. The often unrecognized cost of delays in developing technologies and systems can become dramatically larger than expected. Take, for example, a new material or change that improves the reliability and overhaul time of jet engines on military aircraft. The cost of delay associated with reengining the KC-135 fleet came to $231 million a year (fig. 5). When applied across all engines, such costs could easily reach into billions of dollars a year. The cost of delay remains the same, regardless of whether the delay occurs during technology development or production. The bottom line is that the government should do all it can to limit costly delays by making dynamic changes in funds and offering proper incentives to complete projects with urgency.

Newt Gingrich often refers to government time, indicating that, for example, people have come to accept long lines at the department of motor vehicles that they would find absolutely unacceptable at any commercial establishment. We have grown accustomed to long delays in R&D demonstration programs for defense, but commercial venture capitalists often look for similar results and returns in 18 months or less. By getting answers quickly, they can determine whether a project has

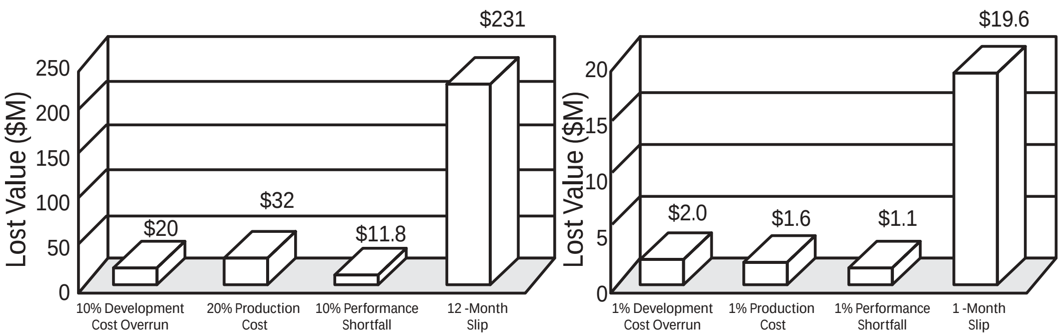


Figure 5. Cost of delay for the KC-135 reengining program. (Adapted from Donald G. Reinertsen et al., "Cost of Delay Analysis: Calculating Project Decision Rules," *Journal of Cost Analysis and Management*, Winter 2002, 14–15, http://www.sceaonline.net/Publications/JOURNAL%202002.pdf.)

commercial potential and limit the amount of money invested to make that determination. A program that produces an answer in 18 months is much more valuable than one that yields the same answer in five years. The longer project would have to generate more than three times the money to realize the same rate of return as the shorter one. This is not to say that the military should undertake only short-term efforts. To do so would eliminate grand (and essential) programs, such as Minuteman and the GPS, that qualitatively change the way we fight. Rather, we need to pursue all programs with a sense of urgency that either delivers quickly or fails, freeing up funding for other efforts. Unfortunately, the current military acquisition system tends to take five years to field even the simplest of systems (i.e., those that should take only a few months), and substantial projects take decades. Most of that time is spent in the advocacy and strategic-planning phases, both of which could easily be skipped or greatly abbreviated.

Don Reinertsen, one of the nation's leading product-development consultants, has definite ideas about tempo. When a participant at the Program Executive Officer / System Commander (PEO / SYSCOM) Conference of 1999 stated, "You cannot speed innovation," Reinertsen responded by asking, "What would you do if you wanted to slow innovation down? You would inadequately fund it, assign inadequate staff, and load that staff with lots of additional, unrelated duties. Given your resourcing and staffing processes, what makes you think that we have gotten those aspects right and cannot speed up your innovation?"[8]

Agile organizations do not "seize the day" by asking their folks to purchase test equipment by filling out a Form 9 purchase request and then stop work repeatedly to chase the paperwork through the procurement bureaucracy. Rather, they risk the cost of the equipment, order it with overnight shipping, and get the team back to work. And such organizations don't require that all funding requests be submitted two years in advance, as does a slow, bureaucratic process like PPBS so it can align all of the associated stakeholders before work can begin. Because time is indeed money, an effective R&D organization cannot afford to waste time. Agile organizations make the most of their time because to waste time is to squander opportunities. Time is always important in military-development efforts. A timely answer regarding the readiness of a particular technology or project can lead to its inclusion or exclusion in a larger system-development effort and thus eliminate parallel design tracks. The reduction in uncertainty can dramatically reduce considerations of potential designs.

Conclusion

The fact that FIRST principles provide agility for an R&D organization becomes particularly important in the new economic environment. Because these principles stress opportunity, they urge aggressiveness with respect to time. For the government, following these principles would require significant change in its current practices. Thus far, government efforts at R&D "reform" have proceeded through contract law, strategic planning, and so forth, in such a way as to minimize financial and programmatic risk by focusing on careful management of money and detailed plans. No clear evidence exists that such reforms have been effective—at least not to the extent advertised. Budgets change too often, and plans are seldom followed. FIRST principles turn the tables—accepting risk in order to seize opportunity and stressing quick action with considerably less regard for fiscal accountability. This proclivity does not imply that FIRST organizations take risks with abandon; rather, they fence them off by doing small things quickly in order to jettison "dry wells" before they sap the organization. These organizations then move on quickly to new opportunities. Opportunity-driven organizations cannot afford to waste time, and they are willing to accept some losses in order to move quickly.

The R&D mobilization that took place during and shortly after World War II offers a good illustration of the benefits of FIRST principles. Overnight, major laboratories, educational centers, test ranges, and organizations were created to build systems of historic significance: the atomic bomb, computer, radar, and many other key innovations. Much of this work was conducted with scanty contracting—sometimes only a handshake. Organizations repeatedly seized opportunities not sanctioned by their official charter (flexibility). They regularly spent unprogrammed money on risky ventures (innovation). Budgets allowed for new opportunities (resources). A massive R&D workforce emerged (support). And everything was conducted very quickly but with patience to see the truly important programs through to the end (tempo). Indeed, despite failed efforts, bad specifications, and occasional waste or fraud, time was always of the essence, and the national effort generally yielded stunning results.

In the 1950s, similarly audacious projects brought about ICBMs, nuclear submarines, the hydrogen bomb, early precision-guided munitions, and our first space systems. Interestingly, these far-reaching projects were completed on a budget comparable to the one for defense spending today. Not only have our current accountability and careful planning failed to render us immune to unsuccessful efforts, bad specs, and fraud, but we also seem to have paid a price. Evidently, our methodical pace does not provide us a technological edge, and we find ourselves leaning increasingly on commercially developed technology. Have our reforms really been worth the cost in terms of opportunity?

Today the Air Force technological establishment continues to deliver results in the face of persistent funding pressures and challenges in hiring and keeping talent. However, one wonders what the service could do if it were allowed to pursue opportunities without restriction. Its challenges are typical of those that face large R&D organizations, but the consequences are far more serious in military organizations. On the one hand, if a company loses its technological edge and misses an opportunity, a competitor—perhaps a smaller company with a newer, more agile, and unfettered R&D system—will exploit the loss, but life goes on for the both of them. The Air Force, on the other hand, absolutely cannot afford to lose its opportunities to the "competition" because the consequences can literally mean the difference between life and death. □

Notes

1. Although the term *some* is rather nebulous, the authors refer to remarks one commonly hears from senior leadership and operational forces within the Air Force. No doubt one would find similar criticisms in commercial industry as well. For example, the staff in Xerox's PARC subsidiary frequently lamented the lack of appreciation from the "copierheads" who ran the parent company.

2. Industrial Research Institute, *IRI's R&D Trends Forecast for 2003,* November 2002, 3, http://www.iriinc.org/webiri/publications/trends2003.pdf.

3. *In Search of Excellence: Lessons from America's Best-Run Companies*, videocassette (Schaumburg, IL: Video Publishing House, John Nathan and Sam Tyler Productions, Harper & Row/Warner Books, 1985), based upon the book of the same title by Thomas J. Peters and Robert H. Waterman Jr. (New York: Harper & Row, 1982).

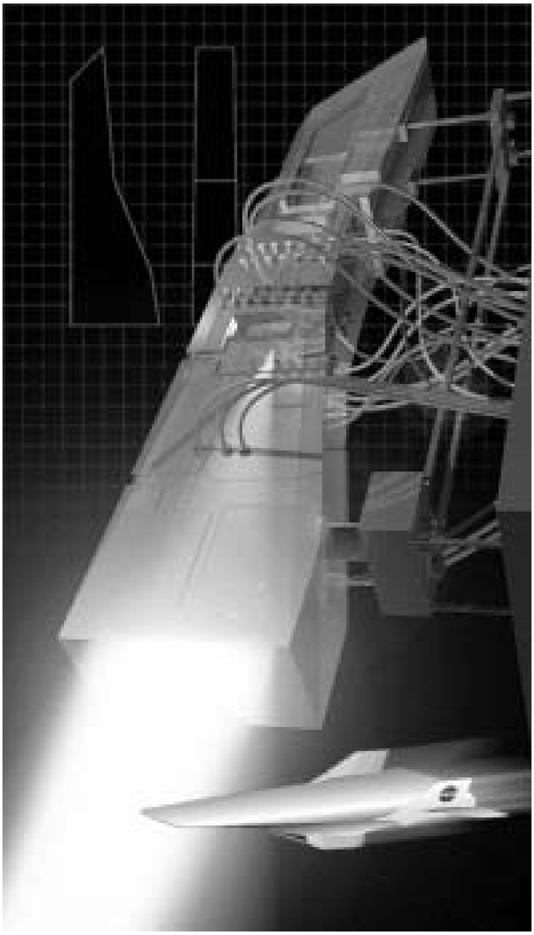
4. See David E. Rumelhart, James L. McClelland, and the PDP Research Group, *Parallel Distributed Processing*, vol. 1, *Foundations* (Cambridge, MA: MIT Press, 1986).

5. The Air Force's S&T funding experienced an increase in FY03 and FY04, a phenomenon that merits a closer look. Although this appears to reverse a downward trend, careful examination reveals a possible change in accounting procedure for funding the service's classified programs. A recently added program element accounts for $369 million or 21 percent of the 27 percent increase in FY04. Although these funds will likely be used for S&T, the important point is that the accounting procedure for classified S&T has changed—not the funding itself—which does not translate into a significant increase in traditional S&T funding.

6. Lt Col Steven C. Suddarth, "Solving the Great Air Force Systems Irony," *Aerospace Power Journal* 16, no. 1 (Spring 2002): 11.

7. See Lt Col David Arreola and Nancy A. Soper, *Air Force Scientist and Engineer Career Field Focus Group Findings*, prepared for the Air Force Science and Engineer Career Field Policy Council, April 2001, http://www.afpc.randolph.af.mil/cp/secp/Documents/Synopsis%20of%20Focus%20Group%20Results.doc.

8. Donald G. Reinertsen, Reinertsen and Associates, PEO/SYSCOM Conference, Cycle-Time-Reduction Session, Defense Systems Management College, Fort Belvoir, VA, 1999.



Powering the Future

Advances in Propulsion Technologies Provide a Capability Road Map for War-Fighter Operations

MAJ MICHAEL F. KELLY, USAF, RETIRED

Editorial Abstract: Gen Hap Arnold's commitment to "preeminence in research," the belief that technology superiority leads to air and space superiority, remains the hallmark of Air Force culture. Air Force success in providing the nation with a rapid air and space response capability requires researchers to continue to provide advancements in a number of technologies. Propulsion and power solutions for aircraft, weapons, and space systems are especially important technologies and are recognized as critical enablers, also making the test facilities that support the research and development of those revolutionary and transformational technologies critical to our progress.

GEN HENRY H. "Hap" Arnold, architect of American airpower, said it plainly and persuasively nearly six decades ago, "The first essential of air power is preeminence in research." That simple, yet prescient statement in the early, heady days of flight revealed Arnold's vision for aeronautical research and development that went on to profoundly shape the future Air Force.[1] By combining his vision, political savvy, piloting skills, and engineering knowledge, Arnold was able to forge a mission and place for the US Air Force. As one of the country's first to earn his military aviator wings from the Wright brothers, he was especially interested in the development of sophisticated air and space technology that could give the United States an edge in achieving air superiority. Arnold went on to foster the development of such transformational innovations as jet aircraft, rocketry, and supersonic flight.[2]

In many ways Arnold institutionalized a commitment to research that remains evident today as the Air Force upholds a position of technological leadership—leadership that delivers a steady infusion of new technology to war fighters through high-risk, high-payoff research in the Air Force Research Laboratory (AFRL). More importantly, his vision of building technological superiority laid the foundation for our capacity to achieve today's Air Force distinctive capabilities—air and space superiority, information superiority, global attack, precision engagement, rapid global mobility, and agile combat support. Arnold's commitment to technology superiority remains the hallmark of Air Force culture.

For over 85 years, Propulsion Directorate scientists, engineers, support personnel, and contractors have been answering Arnold's call for world-class research that puts capabilities into the hands of Air Force war fighters to help them dominate air and space—now and in the future. Its 450 ongoing programs, over 1,000 people, and an annual budget of more than $300 million not only have provided a complete spectrum of advanced propulsion technologies for aircraft, rockets, and spacecraft but also have conducted leading-edge research and development in air and space fuels, propellants, and power systems.[3] Their inventions have expanded the envelope of propulsion technologies and pushed air and space vehicles higher, faster, and farther—even into space—than Orville and Wilbur Wright ever could have imagined. Today, those technologies are flying in air and space on more than 130 military and commercial systems, including the F/A-22 Raptor, the newly christened F-35 Joint Strike Fighter (JSF), and the twin Mars rovers—*Spirit* and *Opportunity*, which successfully landed and began their explorations on the red planet in January 2004.[4] This article discusses mainly the directorate's efforts and their actual and potential impacts—efforts that have been accomplished, are in progress, and are planned for the future.

Technological advancements in the early days of flight brought a whole new set of challenges, and history books confirm the key role that propulsion technologies played in meeting those challenges and in the nation's many air and space accomplishments. The late Melvin Kranzberg, professor of history at Case Western Reserve University in Cleveland, Ohio, said the technical innovation in the Wright brothers' airplane quickly necessitated additional technical advances to make it more effective.[5] Those advances in engines, cooling systems, propellers, power systems, and fuel were closely linked to the Power Plant Section at McCook Field in Dayton, Ohio—first home to the Army Air Corps's aircraft-engineering functions and great-grandfather to today's Propulsion Directorate. The innovations in propulsion and power that were inspired by the Wright brothers and accomplished through the years at McCook Field, Wright Field, and later, Wright-Patterson Air Force Base, Ohio, and Edwards Air Force Base, California, dramatically changed the course of aviation and its applications.

In the air and space age, propulsion research and development capabilities will continue to be of even greater and more urgent importance. F. Whitten Peters, former secretary of the Air Force and now vice-chairman of the Commission on the Future of the US Aerospace Industry, agreed with the judgment reached by that commission in 2002 that propulsion is the crucial enabler to the nation's future air and space capabilities. The commission reached that conclusion after meeting with over 100 companies, government organizations, and interest groups, having heard from more than 60 witnesses and spoken with the government and industry representatives from seven foreign countries.[6]

With an eye on maintaining and strengthening future capabilities, the nation must build a rapid air and space response force enabling robust, distributed military operations across the service's core competencies.[7] As has been true in past endeavors, the long-term challenge in building a rapid air and space response capability will be developing the technologies that enable quick reaction to war-fighter operations or crises wherever needed, much like those Arnold envisioned in the early days of flight.

Meeting and overcoming this challenge will require significant innovation. Already, scientists and engineers can imagine exciting possible solutions as current technology matures—from superconducting power generation that enables high-power, directed-energy weapons to supersonic and hypersonic engines that can power long-range strike aircraft and advanced rocket propulsion and air-breathing hypersonic engines to enable easy access to space. Work is also well under way developing electric-, solar-, laser-, and plasma-propulsion systems for mini- and microsatellites of the future.

While many of these technologies may seem like science fiction, so too were the jet engine, the airplane, and the rocket engine only 100 years ago. Fifty years from now, some of these new technologies may still seem like science fiction, but others will have moved into the realm of the possible. The task at hand for today's scientists and engineers is to perform research that identifies those breakthrough technologies and moves them from science fiction to science fact.[8]

Propulsion and Power for Aircraft

If the Air Force is to succeed in providing the nation with a rapid air and space response capability, researchers must provide a number of technologies including a focus on propulsion and power solutions for aircraft, weapons, and space systems.[9] Although it is important to recognize propulsion as a critical enabler, so too are the test facilities that support the research and development of these revolutionary and transformational technologies.

Revolutionary Propulsion and Power for Aircraft

Propulsion researchers are already testing one of the most promising technologies supporting this capability: a supersonic combustion ramjet, or scramjet, engine that uses conventional jet fuels to reach hypersonic speeds—speeds over Mach 5. With technology of this type the Air Force could deliver a useful payload anywhere on Earth in a few hours, providing a force tailored to accomplish national objectives rapidly anywhere on the world's surface and in the near-Earth air and space domain.

This new scramjet technology has the potential to power future hypersonic vehicles, such as cruise missiles and long-range strike and reconnaissance aircraft, at speeds up to eight times the speed of sound. While today's aircraft and missiles only fly up to the Mach 3 range, new hypersonic aircraft and weapons would offer a faster response to war fighters, giving them the ability to take out time-critical targets within a few hours, if not minutes.

Dubbed "HyTech," for hypersonic technology, the program got its start in 1995 in the wake of the cancelled National Aero-Space Plane program—an effort aimed at developing a hydrogen-fueled, scramjet-powered, single-stage-to-orbit vehicle capable of aircraftlike horizontal takeoffs and landings. In contrast, the Air Force's version of the scramjet is designed to run on JP-7 fuel, a more logistically supportable fuel than hydrogen. While the National Aeronautics and Space Administration (NASA) continues to pursue the development of a hydrogen-fueled system with its "Hyper-X" program, the Air Force, by using hydrocarbon fuels like JP-7 instead of hydrogen, hopes to one day deploy these systems anywhere, anytime, and anyplace.

Wind-tunnel tests on the engine, completed in June 2003, successfully demonstrated the operability, performance, and structural durability of the scramjet system. Building on more than 2,000 tests from components through an integrated, flight-weight engine, the directorate's scientists and engineers, as well as contractors from Pratt and Whitney and the United Technology Resource Center, have demonstrated that the engine works, and they are excited about extending this technology to systems that will give war fighters a distinct advantage over future enemies. With 25 runs at Mach 4.5 and Mach 6.5, the flight-weight engine reliably produced significant net positive thrust, which is important because it demonstrates the ability to efficiently burn fuel and accelerate a vehicle at these speeds. The thermal characteristics and structural durability of the engine were also validated at both speeds.

Another propulsion team is exploring the pulsed detonation engine, or PDE—a new type of engine which may well be the first of its type to power an aircraft in flight. For years, propulsion researchers around the world have searched for a better, more efficient way to increase speed and improve the performance of aircraft. They believe that the PDE may one day fill that critical gap in

America's ability to reach simple, low-cost, high-speed flight. Today, the PDE these researchers have developed creates thrust by using a series of controlled explosions of fuel and air in detonation tubes that look like long exhaust pipes. By designing a process in which the detonations of the fuel and air mixture are controlled, researchers were able to develop sufficient thrust to power future aircraft. The propulsion team is well on its way to proving the PDE concept as an inexpensive, simply constructed, and more efficient engine for tomorrow's war fighters. In fact, the PDE could bring a new level of efficiency and thrust capability to propulsion systems in the Mach 2 to Mach 4 range by improving fuel economy, demonstrating high thrust-to-weight ratios, and simplifying the engine's mechanical structure.

Evolutionary Propulsion and Power for Aircraft

The directorate is also pursuing improvements in more traditional turbine engine technologies to improve performance and reliability while reducing sustainment costs. Turbine engine research, development, acquisition, and sustainment are major Department of Defense (DOD) businesses with a collective annual investment of more than $5.7 billion, excluding fuel cost. Sustainment consumes 62 percent of that budget—more than $3.5 billion—which is why the Air Force's science and technology leaders place such great emphasis on reducing those costs.[10] Keeping sustainment expenses in check is one of the goals of the air-breathing propulsion technology efforts in progress today, as well as those currently in the planning phases.

The Army, Navy, Air Force, Defense Advanced Research Projects Agency (DARPA), NASA, and major US engine manufacturers have been jointly developing and demonstrating cutting-edge propulsion technologies for over a decade under the Integrated High Performance Turbine Engine Technology (IHPTET) program. That program has the goal of doubling propulsion-system capability and reducing acquisition and maintenance costs 35 percent by 2005. IHPTET technologies not only have successfully transitioned into many of the Air Force's legacy propulsion systems powering today's frontline military aircraft, but also are providing the enabling technologies for a wide range of new systems such as the JSF.[11]

Nearly every technology developed under the IHPTET program can, in some way, transition to the commercial sector to improve the performance, reliability, life, and operational cost characteristics of commercial turbine engines—in aircraft, marine, and industrial applications. These contributions help sustain the positive balance of air and space trade and maintain US market share in today's highly competitive, global economy. Without IHPTET program success, aggressive propulsion-technology development programs sponsored by world competitors would quickly challenge the US military and economic advantage in turbine propulsion.[12]

Recent IHPTET successes are providing technologies that allow critical modernization of the F100, F110, and F404 families of engines—the backbone of Air Force frontline aircraft. Also, the knowledge necessary to fix problems currently encountered in the engines of the Air Force, Navy, and Army operational fleets is available because of IHPTET achievements. For example, IHPTET provided the key fan technology for the F118 engine powering the B-2 and demonstrated viability of the majority of technologies chosen for the F119 engine in the F/A-22. IHPTET is also the critical base for all JSF propulsion concepts and other new engines, such as the F414 powering the F/A-18E/F Super Hornet.[13] As a result of these recent accomplishments, turbofan and turbojet designs now being developed can achieve a 40 percent increase in thrust-to-weight and a 20 percent reduction in fuel burn over baseline engines; turboprop and turboshaft engines can attain similar results with a 40 percent gain in horsepower-to-weight and a 20 percent improvement in specific fuel consumption; and air-breathing missile engines can have a 35 percent increase in thrust-to-airflow, burn 20 percent less fuel, and cost 30 percent less.

The performance improvements demonstrated in IHPTET efforts are also being traded to provide increased component lives or cost reductions in fielded systems. The third-phase goal of gaining a 100 percent increase in thrust-to-weight capability will enable specific system payoffs such as sustained Mach 3+ in an F-15–sized aircraft; greater range and payload in an F-18–sized, short takeoff and vertical landing (STOVL) aircraft; a 100 percent range and payload increase in a CH-47–sized helicopter; and intercontinental range in an air launched cruise missile (ALCM) sized missile.[14]

Next-Generation Turbines

Building on the IHPTET's successes, the Versatile Affordable Advanced Turbine Engine (VAATE) program is focused on achieving a tenfold improvement in turbine engine affordability by the year 2017 through a joint DOD, NASA, Department of Energy, and air and space industry effort. In parallel with increases in turbine-engine capability, the VAATE program places major emphasis on research and development, production, and maintenance costs. Its engines will contain numerous technology innovations, providing the war fighter the most versatile and affordable propulsion for legacy (F-16, F-15, and B-1), pipeline (F/A-22, F-35, unmanned combat aerial vehicle [UCAV]), and future military systems (long-range strike aircraft, global-reach transport, and supersonic UCAVs).[15]

For the future, VAATE technologies will assure further dramatic improvements in turbine-engine affordability, not only for military applications such as aircraft, rotorcraft, missiles, and unmanned air vehicles (UAV), but also for America's domestic applications. VAATE attributes include an integrated inlet system; a low-emission combustion system; long-life, high-temperature turbines; high-temperature bearings and lubricants; and an automatic, adaptive-engine health-management system.

The VAATE program is now an approved DOD technology objective and recently awarded its first major procurement activity to multiple defense contractors for approximately $350 million. Contracts are focused on material systems, advanced-fuel technology, and other system technologies required to enable a supersonic, long-range strike capability.[16]

Electrical Power for Aircraft

A revolutionary transformation in aircraft electrical-power technologies that promises greater aircraft reliability and a significantly smaller logistical tail to support tomorrow's air and space force is under way. The More Electric Aircraft (MEA) program is a reality that has been demonstrated in the newly christened F-35 JSF. By teaming with sister services, universities, and air and space industry partners, the directorate's power-technology researchers have translated three decades of technological progress into stunning advances that promise greater war-fighter capability and a 20 percent reduction of aerospace ground equipment (AGE).

The fundamental transformation uses electrical power to drive aircraft subsystems currently powered by hydraulic, pneumatic, or mechanical means. It provides aircraft designers with more options to power gearboxes, hydraulic pumps, electrical generators, flight-control actuators, and a host of other aircraft subsystems.[17] New concepts like electric environmental control and electric fuel pumps, along with magnetic bearings for generators and eventually "more electric" turbine engines, are in the works. They promise dramatic simplifications in aircraft system design, while improving reliability and maintainability in the years to come.

The MEA effort also promises to reduce the bulky and heavy AGE required at home and downrange during deployments and contingencies. Currently, the AGE that supports 24 F-16 Falcons includes electric generators, hydrazine servicing carts, air conditioners, high-pressure air carts, and hydraulic-fluid "mules"; 16 C-141 Starlifters are required for its transport. There could be a reduction of up to 20 percent in the size and weight of equipment required to support MEA units; the freed airlift could be used to transport other war-fighting assets.

Other Propulsion and Power Applications

To succeed in providing the full spectrum of rapid air and space response, Air Force researchers must provide a number of technologies that include a focus on propulsion and power solutions for weapons and space systems. As with other efforts, the directorate is collaborating with other government agencies, industry, and academia to develop, demonstrate, and transition propulsion and power technologies for use in these applications. Those efforts have the potential for evolutionary and revolutionary developments in a variety of air-breathing weapons, hypersonic and supersonic cruise missiles, airborne directed-energy weapons, rocket-powered missile systems, intercontinental ballistic missiles (ICBM), space launch, tactical missiles, and spacecraft propulsion.

Propulsion and Power for Weapons

The most strenuous near-term weapons application is for a scramjet-powered, fast-reaction, long-range, air-to-ground missile cruising at greater than Mach 6—more than 4,500 mph. That missile could be launched from a bomber or fighter, and its rocket booster would accelerate it to speeds of about Mach 4 where its scramjet would start and continue its acceleration to a cruising speed above Mach 6. Although its maximum flight duration is about 10 minutes, it flies seven times faster than a conventional cruise weapon to quickly cover hundreds of miles to reach time-critical targets. A single shooter employing this hypersonic weapon can cover 49 times the area reachable with a conventional cruise weapon.

In the supersonic realm of weaponry, the VAATE program discussed earlier will enable a supersonic, long-range, modular cruise missile with a Mach 3.5+ cruise capability. This advanced weapon will also provide a rapid response time to target, coupled with a flexible mission profile, by using affordable, reliable, and high-performance turbine engines.

The directorate's work in advanced electrical power and thermal management technologies is also enabling concepts like high-power laser weapons on fighter aircraft, high-power microwave weapons for attacking electronics, and nonlethal millimeter wave technologies that use electromagnetic energy to repel advancing adversaries. Recent advancements have been made in several areas addressing the challenges of supporting these futuristic weapons.[18]

One of the most critical problems facing the future implementation of these directed-energy weapon (DEW) systems is adequate electrical power. Adding DEWs to the warfighter's arsenal would provide the Air Force with a significant transformational capability. Scientists and engineers are aggressively working to mature the technologies needed to package and deliver multimegawatts of power in the confined space of a fighter aircraft or space platform. They are developing a new class of electrical components that operate at higher temperatures, such as switches and capacitors, along with superconductivity and thermal-management technologies. All have shown tremendous progress in recent years. For example, those involved in the developmental testing of diamond-like carbon capacitors say their progress is the most significant in decades. In fact, directorate researchers have enabled the production of capacitors with improved energy density and temperature capabilities that are more than two times better than today's state-of-the-art capacitors. These improvements are crucial for airborne applications of DEW because they offer considerable savings in system weight, improved electrical performance, and the ability to withstand high-temperature operating environments.

The next-generation high-temperature superconducting wire, dubbed YBCO for its molecular configuration of yttrium, barium, and copper oxide, is another key DEW-enabling technology. By using YBCO conductor technology, high-speed and high-temperature superconducting generators can produce megawatts of electrical power while weighing up to 80 percent less than traditional iron-core generators.

Conceptually, one- to five-megawatt power generators would allow the electrical DEW to operate as long as jet fuel is available to turn the turbine engines, thereby providing a "deep ammunition magazine." Aerial refueling would eliminate the requirement to land and rearm the aircraft in a conventional sense. In contrast, the Airborne Laser (ABL) program's platform uses a chemically fueled laser to shoot down ballistic missiles while they are still over an enemy's own territory. When all chemical reactants are expended, the aircraft must return to base for reloading.[19]

Propulsion and Power for Missiles

The ICBM is a more traditional weapon with propulsion and power requirements. Although many thought the end of the Cold War would mean the end of the ICBM with its nuclear warheads, this has not been the case. The proliferation of both nuclear and nonnuclear weapons of mass destruction (WMD) into nations and nonstate groups, including terrorists, presents serious challenges to the United States that necessitate the need for a continued nuclear force. However, this nuclear force must have global reach and the capability to be tailored to fit the target's unique requirements. Directorate scientists and engineers, having been involved in every ICBM development since the Atlas and Thor, foresaw this need and continued to pursue improvements in solid-rocket propulsion for next-generation ballistic and tactical missiles. Their $68 million missile research investments gave the Peacekeeper the ability to carry more than twice the payload of the Minuteman III, while fitting within the same silo, and saved the Peacekeeper program over $22 billion, a 32,000:1 return on research investment. Researchers continue to make important improvements in ICBM technologies, allowing the next ICBM to greatly exceed the range of the current Minuteman III.[20]

Propulsion and Power for Space

Scientists and engineers are also focused on the heavens with such collaborative efforts as the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program, a national initiative to improve and double capabilities across the broad spectrum of our nation's rocket propulsion technology by 2010.[21] This program addresses propulsion needs across space launch, ICBMs, tactical missiles, and spacecraft propulsion. It is also one of the few times since the development of the space shuttle main engine more than 30 years ago when the Air Force and NASA are jointly developing reusable rocket-engine boost technology for future DOD and NASA launch vehicles.

IHPRPT teams with industry and focuses their research and development efforts in such areas as new propellants that break through the performance barrier of traditional chemical propellants. Their research and development (R&D) also includes new and more affordable propulsion subsystems for solid rocket motors and liquid-rocket engines; and electric propulsion for satellites; laser propulsion; and solar propulsion for orbit transfer.[22]

A joint Air Force and NASA rocket-engine program called the Integrated Powerhead Demonstrator (IPD) will demonstrate new designs and techniques for application in future liquid-rocket engines to enhance performance and save weight and costs. The program is a combination of research efforts and validation testing to provide new, more efficient portions of the rocket engine that precondition and pump liquid fuels and oxidizers into the main engine. The technology developed under the IPD program will provide the world's first hydrogen-fueled rocket engine with oxygen-rich staged combustion. The IPD test program expects to place a fully integrated engine on the NASA Stennis test-stand facilities for testing in 2004.[23]

While rocket engines have been around for decades, continued research like that being conducted through the IPD test program will lead to a very high return on this investment since propulsion remains a significant percentage of any vehicle's weight and cost. For instance, in space launch vehicles, propulsion accounts for 70 to 90 percent of the vehicle weight and 40 to 60 percent of the system costs. Satellite propulsion represents 50 to 70 percent of the weight and 25 to 40 percent of the costs. Also, a satellite's life span is limited to the lesser of either power or propulsion life, which is why researchers strive to develop smaller, lighter, more powerful, and more affordable propulsion and power systems to improve the capabilities in tomorrow's space vehicles.[24]

These new launch vehicles could eventually meet an on-demand space-surge capability. It stands that if the Air Force could quickly provide joint force commanders with whatever space assets are required, then the Air Force could strategically respond to situations and minimize the need for ultrahigh-resolution worldwide intelligence, surveillance, and reconnaissance assets in predictable orbits. Propulsion researchers are leading the way in arming the country's joint force commanders with the ability to respond rapidly in any given situation by supplying space assets in near real time. This can be accomplished by either launching and maneuvering new assets into place or by moving existing space platforms or weapons to wherever they are required within several hours.[25]

Part of the HyTech program discussed earlier includes an effort to build a durable engine that provides affordable, reusable, on-demand space-access systems. The joint Air Force–NASA X43C program will demonstrate key technologies supporting this application. Conceivably, a two-stage-to-orbit vehicle could take off like a conventional aircraft powered by an advanced turbine engine like those being developed under VAATE and then reach Earth's upper atmosphere by combined scramjet-rocket power to put a payload into space. This concept would provide both ground basing and orbit flexibility at only half the cost of today's approaches, thereby giving the Air Force more affordable access to space.

The nation currently has no truly reusable rocket engines for space launch. The space shuttle engines, based on research from the 1960s, are routinely pulled for maintenance and service after nearly every flight. If we are to achieve operationally responsive space lift by using truly reusable launch vehicles, the nation needs engines that can last a minimum of 50 flights between overhauls. So, while pursuing long-term, high-risk, high-payoff efforts like hypersonic engines for space access, researchers are also pursuing significant advances in liquid-rocket engines. Current and planned programs are developing the materials, components, fuels, and other technologies to enable truly reusable launch vehicles. In the future, hypersonics and rockets will come together in combined cycle engines providing further improvements in performance, cost, and responsiveness. Within 20 years, the nation will see the Wright brothers' vision being taken into space by operationally responsive launch vehicles, which will change the face of battle for many years to come.[26]

In the nearer term, the Air Force has an increased requirement for propulsive microsatellites to support a range of future specialized missions. In conjunction with an operationally responsive space-lift capability, microsatellites could be used to rapidly reconstitute space assets that have failed, ensuring the war fighter uninterrupted service. Individual microsatellites can approach and inspect damaged satellites so the operator can then deploy specialized microsatellites to enact repairs, upgrade electronics, or refill propellant tanks.

Scientists have invented the micropulsed plasma thruster, or microPPT. This miniaturized propulsion system weighs about 100 grams and provides precise impulse bits in the 10-micronewton range. These impulse bits provide attitude control on present 100-kilogram (kg) small satellites and station keeping, as well as primary propulsion on next-generation 25 kg microsatellites. The primary attractive features are the use of a solid, inert propellant (Teflon); expected high, specific impulse when combined with electromagnetic acceleration; and a simple, lightweight design based largely on commercial, flight-qualified electronic components. A comparatively simple version of the microPPT is undergoing flight engineering and qualification for demonstration aboard the US Air Force Academy FalconSat III satellite scheduled to launch in 2006. Five microPPTs are manifested on the flight to increase attitude control for the vehicle.[27]

Conclusion

The intent in facing these technology challenges head-on is to seek out both linear and nonlinear solutions that provide significantly increased capabilities to America's war fighters. The linear challenges will be met with science and technology efforts maturing before 2020, which are continuations of today's current technology. These efforts offer lower risk and modest payoff, and they include reusable boost and orbit-transfer vehicles, solid and hybrid expendable launch vehicles, and satellite propulsion. The service's nonlinear challenges are efforts maturing after 2020 that are new technology breakthroughs involving higher risk but very high payoff. These include space ramjets, magnetohydrodynamics-enhanced propulsion, and directed-energy launches.[28]

While these technology developments could lead to many strategic and force-structure implications, the Propulsion Directorate's goal remains focused on developing new propulsion and power technologies that support the Air Force vision of rapid air and space response. That focus is documented in a mutually supportive and coherent plan for air, space, and energy technologies that covers the next 20 to 50 years. □

Notes

1. C. V. Glines, "Book review of *Hap Arnold and the Evolution of American Air Power* by Dik Alan Daso," *Aviation History Magazine*, http://www.historybookworld.com/reviews/hbwevolutionofamericanairpower.html.
2. Pamela Feltus, "Henry 'Hap' Arnold," History of Flight Essays, US Centennial of Flight Web site, http://www.centennialofflight.gov/essay/Air_Power/Hap_Arnold/AP16.htm.
3. Kristen Schario, "Powering the Future," *Technology Horizons Magazine* (PR-01-08), December 2001, http://www.afrlhorizons.com/Briefs/Dec01/PR0108.html.
4. Ibid.
5. Melvin Kranzberg and Carroll W. Pursell Jr., eds., *Technology in Western Civilization: Technology in the Twentieth Century* (New York: Oxford University Press, 1993).
6. F. Whitten Peters (keynote address, 2002 Turbine Engine Technology Symposium, Dayton, OH, September 9, 2002).
7. Dr. Alan Garscadden and Michael Kelly, "Rapid Aerospace Response: Technological Capabilities Can Provide a Roadmap for War-Fighter Operations," *Technical Horizons Magazine*, December 2003, http://www.afrlhorizons.com/Briefs/Dec03/PR0305.html.
8. Ibid.
9. Ibid.
10. IHPTET brochure, http://www.pr.afrl.af.mil/divisions/prt/ihptet/ihptet_brochure.pdf.
11. Peters.
12. S. Michael Gahn and Robert W. Morris Jr., eds., "Integrated High Performance Turbine Engine Technology (IHPTET) Program Brochure," 2002, http://www.pr.afrl.af.mil/divisions/prt/ihptet/ihptet_brochure.pdf.
13. Ibid.
14. Ibid.
15. IHPTET brochure.
16. Ibid.
17. Michael Kelly, "Power Technologies Create Revolution," *Leading Edge Magazine*, January 2003, 12, https://www/afmc-mil.wpafb.af.mil/organizations/HQ-AFMPC/PA/leading_edge/archives/2003/Jan/JanWeb.pdf.
18. Michael Kelly, "Powering Transformation: Path to Tactical Directed-Energy Weapons Now Reality Thanks to New Power Technologies," *Leading Edge Magazine*, August 2003, 10, https://www.afmc-mil.wpafb.af.mil/organizations/HQ-AFMC/PA/leading_edge/archives/2003/Aug/Augweb03.pdf.
19. Ibid.
20. John Remen, Air Force Research Laboratory Propulsion Directorate, Space & Missile Propulsion Division's strategic development manager, interview by the author, September 2003.
21. Schario, "Powering the Future."
22. "Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Program Background," http://www.pr.afrl.af.mil/technology/IHPRPT/ihprpt.html.
23. Ranney Adams, "Air Force Research Laboratory Leading U.S. Rocket Engine Innovations," *Aerotech News and Review*, July 14, 2003, http://www.aerotechnews.com/StoryArchive/2003/071403/afrl.html.
24. Schario, "Powering the Future."
25. Garscadden and Kelly, "Rapid Aerospace Response."
26. Remen, interview.
27. Dr. Greg Spanjers, "New Satellite Propulsion System Has Mass Below 100 Grams," *Technology Horizons Magazine*, December 2001.
28. Garscadden and Kelly, "Rapid Aerospace Response."

Decentralized Execution
Executing the Mission

The counterweight to air and space power's "master tenet" of *centralized control* is *decentralized execution*. In a balanced operation, these two tenets are critical to the effective employment of air and space power. They are, in fact, the fundamental organizing principles, and decades of experience have proven them the most effective and efficient means of employing air and space power. Decentralized execution balances any command-level tendency toward micromanagement by authorizing subordinates to seize the initiative in dealing with the inevitable uncertainties faced during combat mission execution.

Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms*, defines decentralized execution as the "delegation of execution authority to subordinate commanders." Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine*, provides the specifics for air and space power, stating that decentralized execution of that power is "the delegation of execution authority to responsible and capable lower-level commanders to achieve effective span of control and to foster disciplined initiative, situational responsiveness, and tactical flexibility" (p. 34). When commanders clearly communicate their intent to lower-level echelons, decentralized execution allows those subordinates to exploit opportunities in rapidly changing, fluid situations in a manner that is consistent with the senior commander's overall plan. The theaterwide focus provided by centralized control and the operational flexibility resulting from decentralized execution allows air and space power to best meet the joint commander's theater objectives. It assures a concentration of effort while maintaining an economy of force—exploiting air and space power's versatility and flexibility—ensuring that air and space forces remain responsive, survivable, and sustainable.

Operation Linebacker II (December 1972) is a clear example of the deleterious effect of overcentralizing planning and execution by staffs far removed from the operational environment. Those responsibilities must be delegated to the echelon best suited for the task. As evidenced by several recent operations, modern communications provide a strong temptation to centralize the execution of air and space power. Those command arrangements, however, will not stand up in a fully stressed, dynamic combat environment and should not become the norm for air operations.

Despite impressive gains in data exploitation and automated decision aids, a single person cannot achieve and maintain detailed situational awareness when fighting a conflict involving many simultaneous engagements taking place throughout a large area. A high level of centralized execution results in a rigid campaign that is unresponsive to local conditions and results in the joint effort losing its tactical flexibility. For this reason, a campaign's execution should be decentralized within a command and control architecture that exploits the ability of strike-package leaders, air-battle managers, forward air controllers, and other frontline commanders to make on-scene decisions during complex and rapidly unfolding operations. Nevertheless, in some situations, there may be valid reasons for executing specific operations at higher levels, most notably when the joint forces commander—or, perhaps, even higher authorities—wish to control strategic effects, even if that means the sacrifice of tactical efficiency.

To Learn More . . .

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine*, November 17, 2003. https://www.doctrine.af.mil/Library/Doctrine/afdd1.pdf.

Editorial Abstract: Getting somewhere, sharing information, and producing things all require energy. However, our primary source of energy—oil—is nonrenewable and exhaustible. If we wish to advance, we must seek an alternative, such as hydrogen, the most abundant element in the universe. Fuel cells have the potential not only to transform the future energy needs of the United States and the US Air Force, but also to change how and why we fight.

Fuel Cells

Powerful Implications

LT COL DAVID P. BLANKS, USAF

ENERGY IS THE lifeblood of the global economy. Getting somewhere, sharing information, and producing things all require energy. Throughout the industrial age and into the information age, energy has served as the foundation for mankind's progress. However, our primary source of energy—oil—is nonrenewable and exhaustible. As Kenneth Deffeyes writes, "Fossil fuels are a one-time gift that lifted us from subsistence agriculture."[1] In other words, petroleum products have gotten us where we are, but if we wish to advance, we must look elsewhere for our energy.

Hydrogen, the most abundant element in the universe, represents an alternative source of energy. Indeed, moving from oil-based to hydrogen-based energy sources presents intriguing possibilities. Fuel cells, a current and growing technology that harnesses hydrogen for energy production, are an important part of that transition. To extend the capabilities and operational advantages it needs to confront future challenges, the US Air Force should include research and development of fuel cells and other alternative-energy sources in its transformation strategies. Not only do fuel cells have the potential to transform how the military operates, but also they may change how and why we fight.

Fuel cells have the potential to transform the future energy needs of the United States.

To devise strategies to make that potential a reality, air and space power professionals must review ongoing conflicts over energy and fossil-fuel resources; understand the promise and limitations of fuel-cell technologies; and take advantage of the transformation available through cheap, renewable energy.

Energy and Conflict

Energy resources are major causes of conflict in the modern era—take, for example, the Gulf War of 1991. The United States participated in this UN-sanctioned effort to liberate Kuwait in part because access to energy resources was a vital national interest. The national security strategy of 2000 echoed the importance of such access: "The United States will continue to have a vital interest in ensuring access to foreign oil sources. We must continue to be mindful of the need for regional stability and security in key producing areas . . . to ensure our access to, and the free flow of, these resources."[2] More than a decade after Operation Desert Storm, the national security strategy expresses similar sentiments concerning the importance of energy to the United States and its allies: "We will strengthen our own energy security and the shared prosperity of the global economy by working with our allies, trading partners, and energy producers to expand the sources and types of global energy supplied."[3] As players in the global economy continue to seek alternatives to oil, conflict will either intensify or diminish, thus changing the character and the location of future wars—but not necessarily the motivations. The development and proliferation of fuel cells may not guarantee world peace, but it should reduce our dependence on oil and minimize the role of energy as a source of international conflict.

One can hardly overestimate the importance of the world's supply of fossil fuels for energy needs. The US Department of Energy (DOE) reports that current worldwide oil demand amounts to approximately 74 million barrels per day (mbd).[4] Projected worldwide demand through the year 2020 ranges from a low of 90 mbd to a high of 130.[5] The current estimated worldwide supply of oil ranges from 1 trillion barrels to 1.8 trillion.[6] Given the range of consumption, one could estimate that exhaustion of the supply could occur anytime between the years 2025 and 2050, but this figure can be misleading. Some experts argue that one should examine production capacity in terms of demand—that is, speculate when the production peak will cause demand to outstrip supply.[7] This prediction becomes important because it drives part of the when-and-why discussion for moving from fossil fuels to alternative-energy sources.

Again, estimates vary, but some scientists believe that, under today's conditions—price, distribution ability, political environment, and so forth—approximately 1.4 trillion barrels of economically recoverable oil are available.[8] Assuming that worldwide demand ranges from a low of 75 mbd to a high of 130, the best estimate for when demand begins to outstrip supply occurs somewhere between 2008 and 2020.[9] Oil production will continue, but other economic factors will shape the marketplace. Either the price of crude oil will begin to rise in order to curb demand, or consumers will pay more for a larger share of the available supply. Inevitably, both outcomes will occur to one degree or another.

When the cost of oil exceeds $30 per barrel, alternative-energy sources become more economically viable. Such alternatives cover the gamut—from coal, to nuclear, to solar, to hydrogen—all with their own advantages and disadvantages. In the context of near-term development and exploitation, hydrogen power holds promise as the next major energy source for mankind. In particular, fuel cells offer tremendous potential to meet an ever-increasing energy appetite.

The Nature of Fuel Cells

Fuel cells are miniature power plants that convert the chemical energy inherent in hydrogen and oxygen into direct-current electricity without combustion.[10] Unlike batteries, which store energy, fuel cells produce electricity as long as fuel is supplied. As we will see, the types of available hydrogen fuels vary significantly. Welsh chemist William Grove first proposed developing fuel cells in 1839. As he studied the electrolysis of water—the process of breaking it down into molecular hydrogen and oxygen—he concluded that there must be a way to reverse the process and combine the two elements.[11] Through experimentation, Grove and others laid the foundation for creating efficient fuel-cell energy sources. The idea remains simple: "Harness the chemical attraction between oxygen . . . and hydrogen . . . to produce electricity."[12] Generating electricity by using the two most abundant elements on Earth could provide power to mankind through the next millennium.

The chemistry of fuel cells is straightforward, and all types draw upon the same technology. The proton-exchange membrane (PEM) fuel cell, for example, is composed of an anode (the negative post), a cathode (the positive post), an electrolytic membrane to block electron flow, and a catalyst that facilitates the chemical reaction (fig. 1).[13] With hydrogen flowing across the anode, the catalyst splits the hydrogen into electrons and protons, diverting the electrons to an external circuit to be used as electricity while the protons flow through the membrane. Oxygen is pumped into the cathode side, reacting with the hydrogen protons to form water.[14] Although a single fuel cell produces only a minuscule 0.7 volts, densely stacking PEM fuel cells can produce much greater voltages.[15]

Fuel cells present numerous opportunities for energy production. First, they are inherently more efficient than internal-combustion engines because the intermediate step of combustion is eliminated.[16] Second, with pure hydrogen as the fuel source, water is the only emission from fuel-cell reactions. Thus, these devices have the advantage of operating free of greenhouse gas (e.g., methane, carbon dioxide, etc.) and pollutants, thereby satisfying numerous environmental concerns.[17]

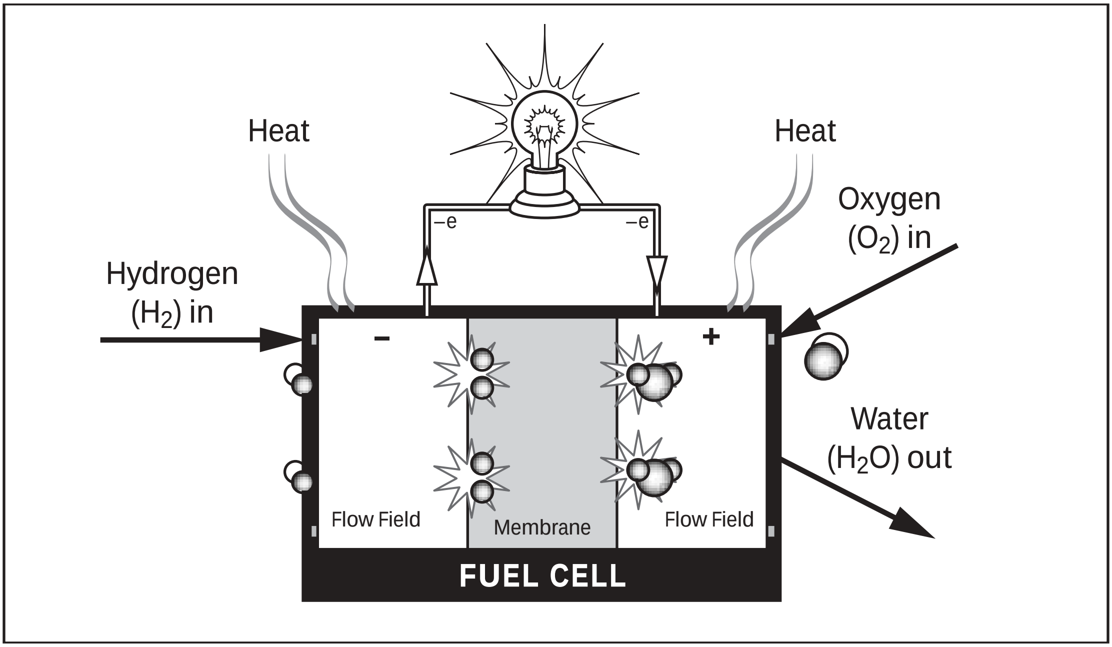


Figure 1. Typical fuel-cell configuration. (Adapted from Sharon Thomas and Marcia Zalbowitz, *Fuel Cells: Green Power*, Los Alamos National Laboratory, http://education.lanl.gov/resources/fuelcells/fuelcells.pdf, 6, 12 [March 3, 2002].)

Finally, since fuel cells are inherently reliable, they could conceivably act as a source of truly distributed power.[18]

Carol Werner notes that "different types of fuel cells are named according to the type of medium used to separate the hydrogen and oxygen."[19] Besides the PEM type, at least four variants exist, each with advantages and disadvantages:

1. Alkaline: principal application in space; operates between 60 and 90° C.

2. Phosphoric acid: used in stationary power applications; operates between 160 and 220° C.

3. Molten carbonate: stationary power, most promising future power-generation technology; operates between 620 and 660° C.

4. Solid oxide: power generation operating at highest temperatures of 800–1,000° C.[20]

Although the promise of cheap, abundant power sounds exciting, the true test comes in demonstrating practical energy-production capability. Since the National Aeronautics and Space Administration began using alkaline fuel cells in the early 1960s, tremendous progress has been made in decreasing their size and increasing their capacity to produce usable electrical energy. Fuel cells now range in size from microdevices to power-grid-enhancing units. Their future holds even greater efficiencies and more utility.

Faced with the relatively slow and costly incremental advances in chemical-battery technology over the last 50 years, numerous organizations have turned to micro fuel cells "as the hot portable energy source of the future."[21] For example, both the laptop computer and cellular-phone industries are investigating fuel-cell batteries because consumers demand longer battery life and greater reliability. Whereas the life of lithium-ion batteries is measured in hours, fuel cells may deliver energy as long as fuel is available.[22] Many problems remain, however, not the least of which is squeezing sufficient wattage out of an ever-decreasing real estate. Nevertheless, current micro fuel cells are being successfully tested in cellular phones. As consumers search for ways to free themselves from wall plugs and power outlets in cars, companies such as Motorola seek to meet market demands by using micro fuel cells. Among the many challenges for these applications is the fact that the by-products of fuel cells are heat and water, both of which are obviously undesirable to cell-phone users.[23] Overcoming the impediments presented by designing and marketing viable fuel-cell technologies that support consumer products may occupy the research-and-development community for the remainder of the decade.

From micro to macro, fuel-cell usage today ranges from homes, to power grids, to over 30 Department of Defense installations. Even though these fuel cells primarily serve niche markets that demand assured access to power, the fact that these alternative-energy sources have become widely accepted bodes well for their future. Fuel cells in the five-to-10-kilowatt (kW) range are available to the consumer-housing market. Meeting the energy needs of a typical four-bedroom home, a 5 kW fuel cell also has the capacity to charge conventional batteries and produce excess power that the owners can sell back to the power grid. Peter Bos, chief executive officer of an energy-consulting company, predicts that "1 percent of U.S. homes will have fuel cells between 2006 and 2010, when a 5kW model will cost roughly $7,000. A few years after that . . . fuel cells will cost only $1,200 and be in half of U.S. homes. By 2031, 99 percent of the homes in the United States won't need to be hooked up to the electrical grid."[24]

At present, office buildings, hospitals, the electrical-power industry, and others can buy fuel cells in the 300 kW, one-and-a-half-megawatt (MW), and 3 MW ranges.[25] Fuel cells presently capture only a tiny fraction of the overall electric market, but they offer many advantages, including cost-competitiveness in shrinking petroleum markets, truly distributed power sources, and favorable environmental effects. Although no one is talking about closing down coal, oil, or nuclear power plants, it is quite conceivable that macro-fuel-cell capacity will continue to grow from megawatt to gigawatt (10^9 watts) capacities. Nevertheless, the largest portion of fuel-cell research—the one most likely to affect the most people in the near future—includes devices used in the transportation industry.

According to a Federal Transportation Advisory Group report entitled *Vision 2050: An Integrated National Transportation System*, "the United States transportation system consumes approximately 12.5 million barrels of oil each day,"[26] nearly two-thirds of the daily national oil usage. Because oil is a nonrenewable resource and because expected demand will outstrip supply well before 2020, as mentioned above, we must do something about our dependence on petroleum: "If just 20 percent of cars used fuel cells, the U.S. could cut oil imports by 1.5 million barrels everyday."[27] Clearly, fuel cells will have their greatest transformational effect in the transportation sector.

Automakers are on the leading edge of developing and exploiting fuel-cell technology. Every major auto manufacturer has or has scheduled a fuel-cell-based car for near-term production. Essentially, such vehicles are electric cars that do not "plug in" each night to recharge their batteries. Rather, they generate electricity from some form of hydrogen-rich fuel. Currently, fuel-cell cars and buses provide mileage ranges commensurate with those of conventional gas-powered vehicles. The principal challenges lie in making these vehicles cost-competitive with those powered by internal-combustion engines and in developing a safe and efficient fuel-distribution infrastructure.

First-generation fuel-cell cars are now available, but fuel-cell-powered airplanes remain a mere twinkle in developers' eyes, although the Boeing Company plans to develop and test a fully electric airplane supplied by fuel cells.[28] Despite this ambitious goal, most developers see only a secondary role for these devices on aircraft. Although hydrogen—liquid hydrogen, in particular—has been used as aviation and rocket fuel, hydrogen-fed fuel cells could generate electricity for equipment such as auxiliary power units. Nevertheless, ongoing studies at the Air Force Research Laboratory foresee unmanned aerial vehicles (UAV) fully propelled and supplied by fuel cells by 2010.[29] These innovative aircraft have the potential to shape strategy for years to come.

Despite the size or capacity of fuel-cell technology, the current debate concerns which form of hydrogen fuel to propagate. The winner in the fuels race will determine the rate of fuel-cell proliferation. Three of the main contenders at this time are pure hydrogen, methanol or other liquid hydrocarbons, and methane (natural gas), each of which presents unique challenges for fuel-cell development and fuel distribution.

Not surprisingly, pure hydrogen is the most efficient fuel for these devices but presents myriad problems associated with making it viable. For example, it is not readily available in nature but most often encountered in compounds in which hydrogen atoms chemically bond to one or more other elements.[30] Separating those bonds takes energy, thereby decreasing the relative efficiencies of fuel cells. Furthermore, the processing, storing, and distributing of pure hydrogen is too difficult in the near term to become globally viable.[31] As one writer puts it, "You don't have a hydrogen pipeline coming to your house, and you can't pull up to a hydrogen pump at your local gas station."[32] Pure hydrogen is simply difficult to obtain, and even when one has it, a great deal of pressure and volume is necessary to store it in order to reap the energy-to-weight efficiencies. Nevertheless, when manufactured renewably (e.g., solar power), pure hydrogen in a fuel cell creates a true zero-emission system, with only heat and water as by-products. In light of the difficulties associated with producing the element in its pure form, however, most fuel-cell developers turn to another alternative for their source of hydrogen.

Since the automotive industry is the primary developer, liquid hydrocarbons lead the way as fuel sources. In particular, much research involves using methanol, whose principal advantage is its similarity to gasoline and, hence, worldwide familiarity with its production, transportation, and distribution.[33] Depending upon their source, liquid-hydrocarbon fuels can also become a renewable energy resource. Disadvantages include storage, corrosiveness, and fuel waste due to "crossover" in the fuel-cell membrane.[34]

Regular gasoline and ethanol are just two of the available liquid-hydrocarbon alternatives, but the need for "reformation" of the fuel prior to introduction into the fuel-cell system remains the constant among all liquid sources. The reforming process extracts hydrogen from the more complex molecular structures; however, the fact that carbon monoxide and carbon dioxide can become additional by-products of the energy-production cycle makes these systems less attractive.[35] While the transportation industry focuses on liquid hydrocarbons, the stationary power-production industry is investigating natural gas as a source of hydrogen.

Most Americans are familiar with natural gas as an energy resource, especially for domestic applications. But few consumers are aware of its uses beyond heating and cooking purposes. As a potential source of hydrogen for fuel cells, natural gas boasts an established delivery infrastructure and significantly reduces greenhouse-gas emissions. Outside that established infrastructure, however, the need to compress natural gas and to use special dispensing equipment reduces its appeal as a source of hydrogen.[36] Lastly, because natural gas is nonrenewable, reliance on it as a fuel offers meager benefits for long-term energy security. But another development promises to make natural gas *the* fuel of the twenty-first century.

Especially worthy of mention are methane hydrates. Methane is "the chief constituent of natural gas."[37] Although no consensus exists regarding the total amount of natural gas discovered and/or producible, one may assume a reasonable figure of 5,000 trillion cubic feet.[38] Additionally, if the accuracy of the US Geological Survey of 1995 is within even one order of magnitude, the US portion of gas-hydrate reserves approaches 200,000 trillion cubic feet.[39] Despite tremendous obstacles, if only a small fraction of these hydrates could be recovered in the form of usable gas, the potential for natural gas as a source of energy takes on staggering dimensions.[40] As a source of fuel for fuel cells, this mother lode presents tremendous opportunities. Whether pure hydrogen, liquid hydrocarbons, or natural gas emerges as the primary source for fuel cells, the development of each is assured.

Scenario-Based Planning

The DOE maintains a division dedicated to hydrogen-fuels research. Within that division, the Hydrogen Technical Advisory Panel (HTAP) conducts scenario-based planning to envision possible hydrogen-fuel developments. In a conference held in 2001, the HTAP identified two main drivers for hydrogen development and proliferation: the rate of social concern and activism and the rate of hydrogen-technology development.[41] The panel developed four quadrants and story lines from these drivers to address the DOE's vision of a hydrogen-fuel-based society. Since the HTAP's work focuses primarily on DOE-related issues rather than Air Force issues, the scenario story lines developed by the panel are not particularly useful for addressing the service's concerns. But by using the HTAP's drivers and the methodology described in the Air Force's study *Alternate Futures for 2025* (1996), one can derive four plausible fuel-cell worlds for the future (fig. 2).[42]

Quadrant A: Greenpeace

Greenpeace is a world characterized by increased awareness of global warming. The inhabitants of Greenpeace—situated at the axes of slow fuel-cell development and high social awareness—have taken to heart the destructive environmental effects brought on by mankind over the industrial age and early portion of the information age. Actively engaged in seeking to reduce greenhouse-gas production, Greenpeace has turned to several alternative forms of energy production to meet a still-increasing worldwide appetite for energy.

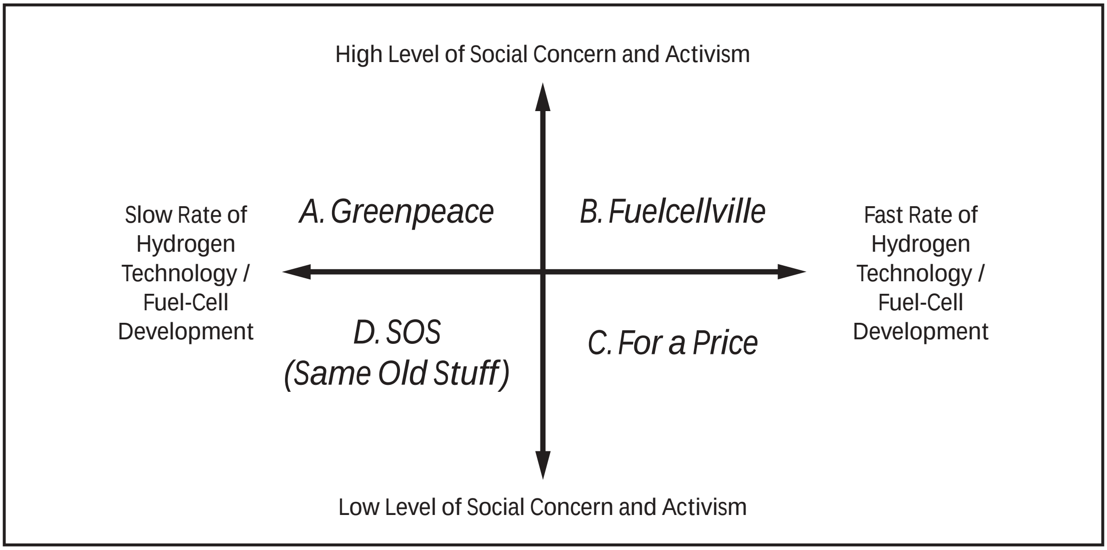


Figure 2. Fuel-cell world quadrants

Plausible History. In the Greenpeace world, social concerns drive energy alternatives. The success of the New Electric Car 5 (NECAR5) initiative prompts the development of NECAR6 (fig. 3).[43] Publicity of the true costs of fossil fuels on the environment makes daily headlines.[44] Although natural gas is a fossil fuel, the campaign promoting cleaner-burning fuels results in quick exploitation of vast reserves of methane hydrates on the US continental shelf in 2010.[45] California's lead in requiring zero-emission vehicles becomes a national model in 2015.[46] By 2020 Air Force base realignment and closure activities result in the consolidation and closing of foreign-operated facilities. Each "superbase" is powered by stationary fuel cells, maintaining autonomy from the commercial power grid.[47]

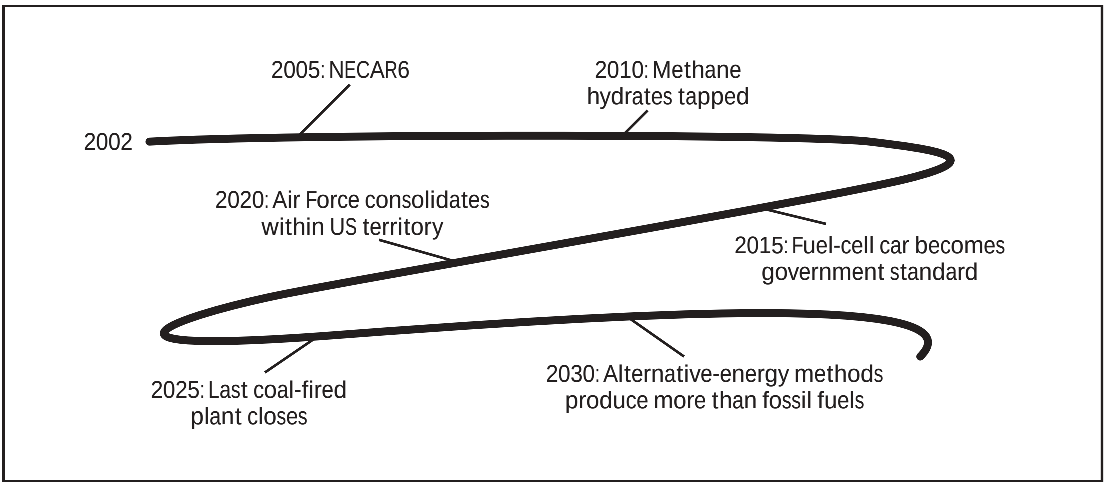


Figure 3. Greenpeace timeline

Concerns over national greenhouse-gas emissions force the closure of the last coal-fired power plant in 2025. Advances in photovoltaics, geothermal energy, and wind-recovery ensure that alternative-energy production eclipses that of conventional fossil-fuel facilities.[48] Greenpeace is marked by slow fuel-cell development as a variety of energy alternatives emerge in a socially aware world.

Capabilities. Fuel cells exist in society and the military; however, their proliferation is but one facet of the alternate-energy equation. In 2002, capacities of 3 MW of stationary power evolved but only to the point where it was economically feasible for government-sponsored organizations to take advantage of this capability. Because the majority of fuel-cell progress occurs in transportation, fuel cells can power nearly all forms of transportation. Nevertheless, fuel cells remain a niche market in external power production as other alternatives emerge.

Implications *for* the Air Force. In a Greenpeace world, environmental concerns affect operations tempo, basing, and training. To satisfy increasing societal awareness, the Air Force will have to adopt energy alternatives. Fuel cells can provide stationary power and meet stationary requirements for deployed forces. But a slow rate of technological development means that fuel cells will continue to fill only secondary roles. The Air Force's fuel-cell investments will continue to leverage other government programs as well as commercial research and development.[49] Finally, since the United States has not yet become self-reliant in terms of energy, it still expends vast sums of money protecting energy supplies.

Implications *against* the Air Force. Adversaries stand poised to take advantage of a Greenpeace world. Our historical indifference to environmental issues can be used against us in a major public-relations campaign directed at Air Force operations. As people worldwide become more socially active, we are apt to find ourselves objects of their ire. Furthermore, a global-environment movement that targets oil use holds danger for energy-producing alliance nations.

Critical Issues and Pathway. The Greenpeace scenario depends upon a dramatic increase in social awareness. How such awareness evolves becomes the key to getting to quadrant A. Assuredly, environmental groups will tout the benefits of fuel cells while decrying the destructive effects of traditional fuel sources. What causes this message finally to take hold may come from one of several sources. First, many countries are more "green" oriented than the United States. If our position in the world diminishes in the coming decades, those external views may become more prominent. Second, as members of a younger, more environmentally conscientious generation mature, their message may begin to take hold as they move into leadership positions. Additionally, if record warm-weather patterns continue, even detractors of global-warming theories may concede that fossil fuels adversely affect the environment. Finally, local, state, and federal governments may lead the environmental cause. The mandating and subsidizing of environmental issues may generate increased social awareness. Fuel-cell technology may make noticeable gains, but without increased social awareness, a pathway to Greenpeace is not possible.

Quadrant B: Fuelcellville

In Fuelcellville high social concerns and a fast rate of fuel-cell technology development converge. Fuel-cell capabilities advance rapidly as nations and corporations eagerly seek alternatives to fossil fuels. As technology development overcomes storage and distribution barriers, economies of scale allow wide proliferation of fuel-cell technology.

Plausible History. The DOE's hydrogen program succeeds in obtaining a massive infusion of federal dollars in 2005 (fig. 4).[50] Social activism brought on by the election of 2008 results in a government mandate that all federal vehicles be powered by direct-methanol fuel cells by 2010. In 2012 the demand for oil exceeds supply, raising the cost of a barrel of oil to $100 and pump prices to five dollars per gallon in 2015.[51] Advances in stationary fuel-cell power result in the Fuel Cell Proclamation Act

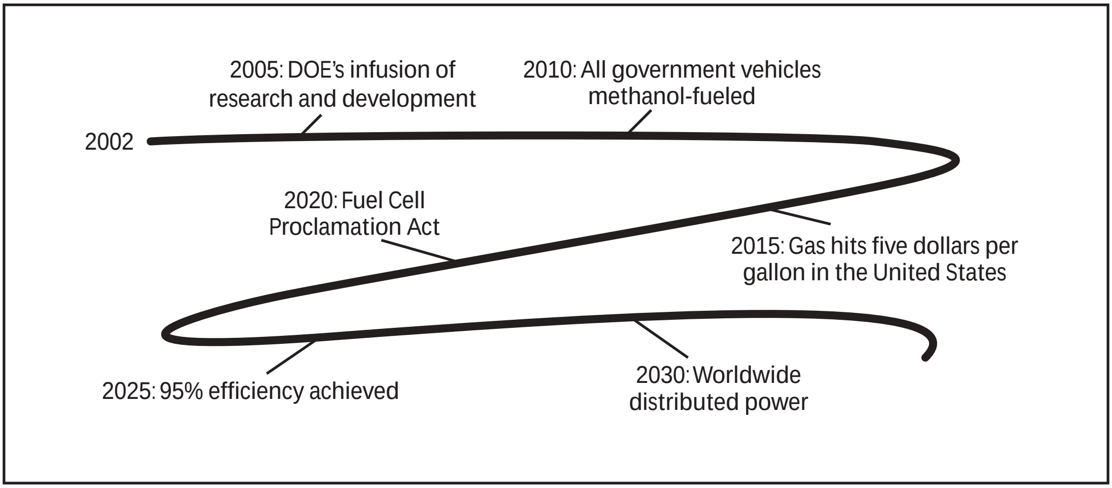


Figure 4. Fuelcellville timeline

of 2020 whereby all government facilities are removed from the power grid and fed by fuel cells. Lower Heating Value efficiencies reach 95 percent in 2025.[52] Fuel-cell technology permeates all four corners of the globe, resulting in a true hydrogen economy and absolute, worldwide distributed power by 2030.[53]

Capabilities. Fuel cells are adopted as the primary means of power production. Society becomes truly all-electric as fossil fuels are abandoned in favor of the rapid development of hydrogen-fuel technology. Portable fuel cells become as common as AA alkaline batteries. The internal-combustion engine goes the way of the covered wagon because vehicles powered by fuel cells meet all cost and performance requirements. Lastly, stationary fuel cells achieve remarkable efficiencies, and a movement away from centrally based power production to distributed power production becomes standard.

Implications *for* the Air Force. In Fuelcellville the Air Force will likely remain at the forefront of the transition from petroleum to hydrogen-based fuels. Large-scale government investment will allow the service to field state-of-the-art fuel-cell equipment, thus decreasing the logistical footprint of deploying forces and reducing overall airlift requirements.[54] The increased reliability associated with electrical versus mechanical equipment means the Air Force will need far fewer maintainers in active service. Effects-based strategy needs to evolve from slogan to practice. Fuelcellville does not diminish the military option; it just transforms how it is powered.

Implications *against* the Air Force. The transition from oil-based to hydrogen-based societies may cause increased tensions in the Middle East. As oil revenues decrease, peacekeeping requirements will likely increase. The primary source of regional conflict will likely shift from petroleum resources to water rights.[55] Distributed power generation worldwide forces a fundamental reassessment of Air Force doctrine. The production of electrical energy is no longer considered a center of gravity because there are simply too many energy facilities. Instead, storage and distribution networks gain increased strategic and operational importance. Finally, in Fuelcellville the increased dependence on electronics and electronic controls increases the vulnerability of Air Force equipment to electromagnetic pulses. Without electromagnetically hardened equipment, everything from transportation to information is subject to disruption.

Crucial Issues and Pathway. The path to Fuelcellville presents the double challenge of increased social awareness and increased technology. Besides the environmental concerns, key technological hurdles must also be cleared. First among these is the efficiency of fuel cells. In the transportation industry, if cars powered by these devices can overcome problems associated with fuel storage, safety, and supply infrastructure, fuel cells will begin to move from government-led efforts to the mainstream. Second, fuel cells cannot achieve widespread public acceptance until they become commercially and economically viable. Government investment must bridge the development costs to true commercial viability and then advertise the successes to encourage new customers and investors to continue.[56] Without an engaged public or three to four technological leaps, establishment of a pathway to quadrant B becomes less likely.

Quadrant C: For a Price

Characterized by low social activism and high technological development, the For a Price world presents fuel-cell opportunities to those who can afford it—namely governments and government-supported industries. While most Americans remain apathetic to decreasing fossil-fuel supplies and deteriorating environmental conditions, other countries—most notably Iceland, Germany, Singapore, and Japan—make rapid advancements in fuel-cell development. The US government and its departments capitalize on these advantages, primarily in the military arena, but overall costs compared to those for fossil fuels keep fuel cells from breaking into the mainstream.

Plausible History. In 2005 the Air and Space Expeditionary Force (AEF) Battlelab's early work on the Common Core Power Production spawns the first full AEF deployment of support equipment wholly powered by fuel cells (fig. 5).[57] In 2010 solar-cell efficiencies allow the Air Force to test the first fuel-cell-powered UAV.[58] The California and New York energy-deregulation experiments of 2000–05 fail miserably, resulting in enactments of government-subsidy programs. To advance additional research, industry leaders switch to a fuel-cell infrastructure for stationary-power distribution in 2015. By 2020 the North Atlantic Treaty Organization (NATO) reaps the benefits of member-nation research and adopts PEM fuel-cell standards for all ground-transportation vehicles.[59] The year 2025 marks the first anniversary of Project Endure—the successful, continuous operation of a fuel-cell-powered UAV.[60] With 176 nation-state signatories to the Kyoto protocols in 2012, fuel cells and other alternative technologies

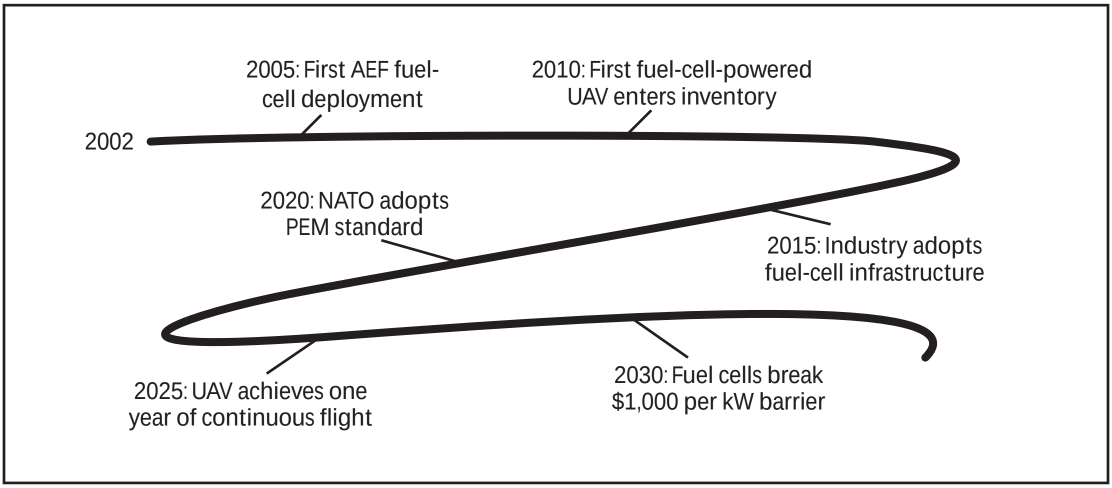


Figure 5. For a Price timeline

advance rapidly. However, since the Middle East and South America still supply 90 percent of the world's oil without interruption or price fluctuations, fuel-cell benefits remain limited to those customers outside the main power grid and other niche markets.[61] Not until 2030 do fuel-cell costs per kW of energy produced break the $1,000 barrier.[62] Fuel cells have been available over the past three decades; however, cost has prevented their introduction into mainstream commercial markets.

Capabilities. Fuel-cell technology makes advances in portable, mobile, and stationary markets. However, American social pacifism prevents widespread concern or desire for environmentally friendly alternatives to fossil fuels. Accordingly, capabilities exist but only to those who can afford them. The US government sees utility in fuel cells and incorporates those technologies into specific military applications that require reliability and persistence. Adoption of common fuel standards for fuel cells allows more concentrated development, which nevertheless remains outside US influence.

Implications *for* the Air Force. The Air Force recognizes that fuel-cell development will not occur without government-led efforts. Even though rapid technological developments will not replace jet fuel in aircraft, the service still needs to capitalize on advances made by other countries in unique mission applications. Specifically, support equipment and UAVs are ripe for fuel-cell proliferation. UAVs powered by these devices allow for spacelike capabilities in persistence with substantially reduced costs.[63] Benefits to the logistical tail run the gamut from maintenance to supply. With fuel-cell-technology applications primarily confined to governments, the Air Force stands to have a significant unilateral benefit in this scenario.

Implications *against* the Air Force. Until costs become competitive with conventional power production, fuel-cell usage is likely to remain confined to governments that can afford them. Because those governments tend to be democratic and because of increasing globalization, fuel cells offer the potential for greater national security. For our adversaries who take advantage of fuel cells in the For a Price scenario, distributed power assumes key importance. Energy infrastructure loses its desirability as a target. But if such targets are in fact attacked, the potential for collateral damage may well exceed the expected payoff or desired strategic effect. As a result, fuel cells become a means to achieve strategic ends against the United States.

Crucial Issues and Pathway. To realize a For a Price world, similar technical breakthroughs to Fuelcellville must occur. Those advancements are likely to come through government involvement because initial costs prevent extensive proliferation. However, the crucial issue in quadrant C remains social apathy. Diverse interests and attitudes keep Americans and the rest of the world largely uninvolved. America is often categorized as a "throwaway" society. Whether their attitude is based in fact or perception, the American public considers the country's environmental policy largely "window dressing" rather than an effective plan. We consume most of the world's energy, yet we comprise less than 5 percent of the planet's population. Our reluctance to engage in environmental negotiations gives rise to world acrimony. Our affluence can make us indifferent to problems beyond our own borders. Additionally, rising nations—be they industrial or informational—spurn environmentally imposed mandates by citing the need for immediate progress rather than long-term effects. Finally, debate continues over the extent to which existing technologies affect the environment; this, in turn, delays the reaching of consensus in addressing problems on a global scale. As long as overall social apathy exists, fuel-cell developments are unlikely to transform the worldwide energy picture.

Quadrant D: SOS (Same Old Stuff)

SOS is a world not too different from the one we live in today, distinguished by a low rate of social activism and low fuel-cell development. Research on alternative-energy technologies remains a minuscule portion of the federal budget. Indifference to the modest 1° C rise in global temperatures over the past three decades has only furthered global-warming debates. Fossil-fuel usage continues as the primary source of energy. Tensions over access to energy sources require continued US defense involvement around the world.

Plausible History. As the federal deficit exceeds $7 trillion, a Balanced Budget Amendment passes in 2005, causing cuts throughout government (fig. 6). Notable among these is the cancellation of all DOE hydrogen projects.[64] Oil-industry leaders, in cooperation with the Russian government, explore the vast Siberian region. An oil find estimated at 10 trillion barrels is announced in 2010.[65] The Organization of Petroleum Exporting Countries responds by increasing production, causing gasoline prices to drop to 50 cents per gallon. In 2015 scientists in Antarctica report that the ozone hole has closed. In contrast to global-warming theories, the apparent cause is tied more to the 1980s ban on chlorofluorocarbons than on greenhouse-gas emissions. The Joint Strike Fighter achieves initial operational capability in 2020 and introduces JP-10 as the fuel standard. Not only does JP-10 meet all engine-performance requirements, but also its energy content is so high and flash point so low that it becomes the standard for auxiliary-power production.[66] By 2025 the Army's transformation process is complete, and a demonstration using a soda-can-sized fuel cell powers an office for one week.[67] Further demonstrations lead to the building of a blimp for the modern age—the *Hindenburg II*—powered solely by fuel cells. However, in 2030 a freak accident reminiscent of the one that destroyed the dirigible's namesake keeps fuel-cell technology confined to niche markets.[68]

Capabilities. Fuel cells remain novelty items for most of the population. Like the progress of conventional battery technology in the last half of the twentieth century, fuel-cell efficiencies make only modest gains. Automobile makers offer fuel-cell alternative cars, but their range and refueling requirements make them less attractive than vehicles equipped with internal-combustion engines. Stationary fuel-cell power generation remains cost prohibitive to all but the most isolated or ecologically minded. The impending oil shortage never materializes, and fuel cells, as well as other energy alternatives, remain on the sidelines.

Implications *for* and *against* the Air Force. SOS is perhaps the most recognizable yet most dangerous of all the worlds discussed here. The Air Force can be expected to main-

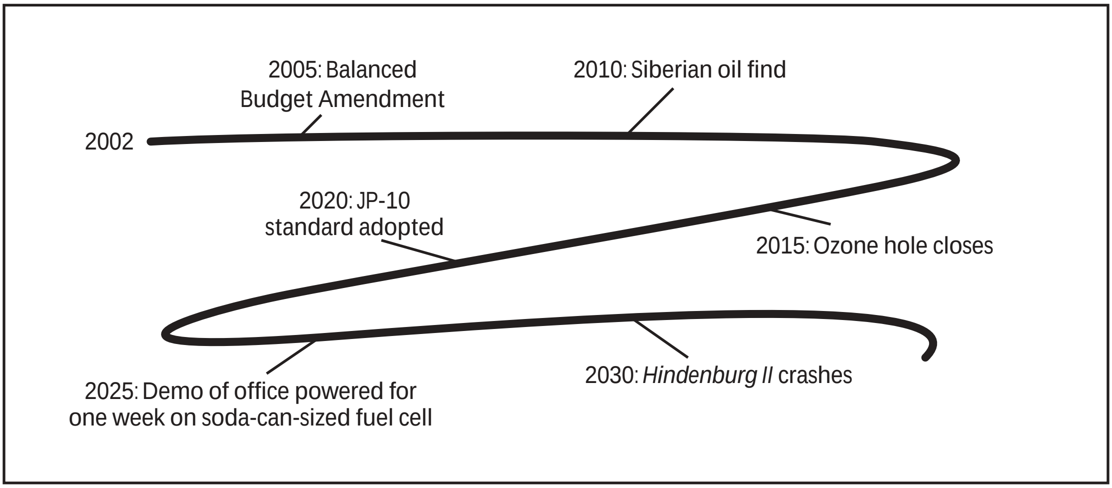


Figure 6. SOS timeline

tain the status quo relative to other nations. No impetus for revolutionary change exists. The notion of transformation or effects-based targeting has the potential to become the next "quality" movement—a mere slogan for each new service chief. Our dependency on foreign oil never wanes. Danger lurks around the globe as other countries make advances in alternative-energy sources and seek alliances based on assured-energy access. How we choose to respond will affect our vision and strategy for decades to come. SOS lives up to its name.

Crucial Issues and Pathway. Since there is little debate that American society currently resides in quadrant D, remaining there means doing little that is different. The critical issue here is research and development. If government and private funding remains at levels similar to those of today, advances in fuel-cell technology are likely to do no more than creep ahead. In addition, myopic environmental reviews both inside and outside government prevent anything beyond grassroots efforts from flourishing. Although the United States might remain within SOS, there is no guarantee that the remainder of the world will do so. It is conceivable that multiple pathways can coexist. Nevertheless, without a combination of social activism and technological advances, transition from fossil-based to hydrogen-based fuels is unlikely.

Future Issues and Applications

Despite claims to the contrary, predicting the future is an inexact art. Each of the fuel-cell worlds considered here can occur, but it is unlikely that any one will unfold exactly as outlined. They do have certain crucial issues in common, however. Specifically, the world's response to the impending oil crisis, whether it occurs 10, 20, or even 100 years from now, will define our energy future. Additionally, whether global society responds to environmental concerns now or delays decisions until some indeterminate future will characterize our willingness to accept short-term gains in deference to long-term effects. These two issues underscore fuel-cell development and proliferation.

The utility of the four future worlds lies not in their predictive value, but in preparing others to think of the possible. Many acquisition decisions made today do not bear fruit for war fighters for years to come. We have the option of behaving either proactively or reactively. By understanding what is possible, we can take positive steps to prepare for the future.

Beginning in the mid-1990s, fuel cells have now been installed at 30 Department of Defense locations.[69] To begin a movement from SOS to any other quadrant, the Air Force must become part of government-led efforts to change to alternative-energy methods. Current fuel-cell technology is too immature and cost prohibitive for pure private-sector development. Through government efforts, fuel cells can move out of the laboratory and onto Main Street, USA.

Additionally, anticipating how adversaries might use this technology remains fundamental to any evolution of our strategy. The Air Force should start preparing now for adaptation and response to fuel-cell-powered societies. Do we continue to target energy infrastructure, as we have done in nearly every conflict since World War II? How do we interdict energy supply lines when the main fuel is not petroleum-based but gaseous, producible in the field, and not under the control of relatively few governments? Do we aid developing nations by allowing them to leapfrog our own industrial mistakes and powering them with sustained energy? These and numerous other questions demand flexibility in our strategy. The Air Force should consider the following steps in order to retain this flexibility:

1. Increase funding in hydrogen technology.
2. Exploit developments made in other government and private sectors.
3. Take risks and rapidly transition technologies in the most promising arenas of both manned and unmanned air vehicles.

4. Increase the percentage of bases powered by alternative-energy sources.

5. Develop war-game scenarios based on the proliferation of fuel cells by both the United States and its adversaries.

Because fuel cells have powerful implications for the military and the world, we must be ready to deal with them.

Fossil fuels cannot sustain the planet's energy appetite indefinitely. Continued access to these resources means additional expense on our part in terms of finances and possible loss of life in defending them. If we are to become what Michio Kaku calls a type-one civilization in this third modern millennium, we must look beyond fossil fuels for our primary energy sources.[70]

Fuel-cell technology is fundamentally sound although it faces many challenging obstacles in the years ahead to achieve its potential. Whether these devices remain curiosities or infuse themselves into the mainstream is yet to be determined. The path to any of the future worlds discussed here is certainly not preordained. However, if we wish to continue to progress, we must begin to capitalize now on what Los Alamos National Laboratory dubs a "once in a lifetime opportunity": fuel cells.[71] □

Notes

1. Kenneth F. Deffeyes, *Hubert's Peak: The Impending World Oil Shortage* (Princeton, NJ: Princeton University Press, October 2001), i.
2. *A National Security Strategy for a Global Age* (Washington, DC: The White House, December 2000), 34.
3. *The National Security Strategy of the United States of America* (Washington, DC: The White House, September 2002), 19–20.
4. Department of Energy, http://www.eia.doe.gov/oiaf/ieor (accessed April 7, 2002).
5. Ibid.
6. Geohive, http://www.geohive.com/charts/energy_oilres.php (accessed February 28, 2002).
7. Deffeyes, *Hubert's Peak*, i.
8. Geohive.
9. Review of Deffeyes, *Hubert's Peak*, http://www.amazon.com (accessed April 7, 2002).
10. Carol Werner, "Fuel Cell Fact Sheet," Environmental and Energy Study Institute, February 2000, http://www.eesi.org/publications/02.00fuelcell.pdf, 1 (accessed March 15, 2002).
11. Alan Leo, "Fuel Cells in Brief," *Technology Review*, February 5, 2002, http://www.technologyreview.com/articles/wo_leo020502.asp, 2 (accessed February 11, 2002).
12. Ibid.
13. Karim Nice, "How Fuel Cells Work," in Marshall Brian, *HowStuffWorks*, http://www.howstuffworks.com/fuel-cell.htm, 2 (accessed January 31, 2002).
14. Sharon Thomas and Marcia Zalbowitz, *Fuel Cells: Green Power*, Los Alamos National Laboratory, http://education.lanl.gov/resources/fuelcells/fuelcells.pdf, 4 (accessed March 3, 2002).
15. Ibid., 7.
16. Werner, "Fuel Cell Fact Sheet," 1.
17. Thomas and Zalbowitz, *Fuel Cells*, 27.
18. Werner, "Fuel Cell Fact Sheet," 2.
19. Ibid., 3.
20. Peter Hoffman, *Tomorrow's Energy: Hydrogen, Fuel Cells, and the Prospectus for a Cleaner Planet* (Cambridge, MA: MIT Press, 2001), 156–57.
21. Steven Ashley, "Fuel Cell Phones: Portable Power from Fuel Cells Inches Along," *Scientific American*, July 2001, http://www.sciam.com/2001/0701issue/0701scicit4.html, 2 (accessed January 31, 2002).
22. David Voss, "A Fuel Cell in Your Phone," *Technology Review*, no. 9 (November 2001): 69.
23. Ibid., 70.
24. Quoted in Charles Wardell, "Dreams of the New Power Grid," *Popular Science* 260, no. 3 (March 2002): 62.
25. Ballard Power Systems, http://www.ballard.com (accessed April 7, 2002).
26. US Department of Transportation, *Vision 2020: An Integrated National Transportation System*, February 2001, http://scitech.dot.gov, 7 (accessed March 16, 2002).
27. Werner, "Fuel Cell Fact Sheet," 2.
28. "Boeing to Explore Electric Airplane," Boeing Company news release, November 27, 2001, http://www.boeing.com/news/releases/2001/q4/nr_011127a.html (accessed January 31, 2002).
29. Thomas Reitz, Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson AFB, OH, telephone interview by the author, March 27, 2002. Subsequent electronic message contained unpublished paper and briefing.
30. Nice, "How Fuel Cells Work," 3.
31. Thomas and Zalbowitz, *Fuel Cells*, 19.

32. Nice, "How Fuel Cells Work," 3.

33. Thomas and Zalbowitz, *Fuel Cells*, 17.

34. Ibid.

35. Ibid., 19.

36. Ibid.

37. US Department of Energy, Office of Fossil Energy, "Methane Hydrates," http://www.fe.doe.gov/programs/oilgas/hydrates, 1 (March 11, 2002).

38. US Department of Energy, table, http://www.eia.doe.gov/emeu/iea/table81.html (accessed April 7, 2002).

39. US Department of Energy, "Methane Hydrates," 2.

40. Ibid.

41. Jim Ohi, "Enhancing Strategic Management of the Hydrogen Option: Scenario Planning by the DOE Hydrogen Technical Advisory Panel" (proceedings of the 2001 DOE Hydrogen Program Review), 3.

42. Joseph A. Engelbrecht Jr. et al., *Alternate Futures for 2025* (Maxwell AFB, AL: Air University Press, September 1996), 9–17.

43. See United Press International, "Bush Views Hybrid Vehicles," http://www.home.knology.net/news.cfm?id=1362 (accessed February 25, 2002), for speculation about future proliferation of fuel-cell vehicles.

44. See "Benefits of Fuel Cell Transportation," http://www.fuelcells.org/fct/benefits.htm (February 21, 2002), for a statement that for every gallon of gasoline manufactured, distributed, and consumed, roughly 25 pounds of carbon dioxide (CO_2) is released.

45. Natural-gas consumption in the United States will increase to more than 32 trillion cubic feet by 2020. US Department of Energy, "Methane Hydrates," 2.

46. By 2003 10 percent of vehicles must be of the zero-emission type. Extrapolated to 2015, the number comes to approximately 100,000. Thomas and Zalbowitz, *Fuel Cells*, 29.

47. See Ballard Power Systems for predictions concerning the capacity of stationary fuel cells.

48. See "Power Till the Cows Come Home," *National Geographic* 201, no. 4 (April 2002): xxiii–xxiv, for information about unused wind capacity worldwide.

49. Briefing, Col Al Janiszewski, US Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson AFB, OH, to EL-636 class, March 11, 2002. Research dollars for fuel-cell work are localized within the directorate.

50. See Ohi, "Enhancing Strategic Management," 11, for HTAP recommendations for future investment.

51. See review of Deffeyes, *Hubert's Peak*, for speculation about Hubert's Peak coming to fruition and consequences for worldwide oil prices.

52. See Joseph Fellner, Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson AFB, OH, interview by colleague Dr. Thomas Reitz, March 27, 2002; and idem, briefing, "Fuel Cells for Persistent Area Dominance (PAD) Concept," chart 10, January 15, 2002, for speculation about increased efficiencies in out-years.

53. See Hoffman, *Tomorrow's Energy*, 247–64, for six scenarios that converge on hydrogen proliferation.

54. Thomas J. Piro, *Common Core Power Production (C2P2)*, written for Air and Space Expeditionary Force Battlelab, November 15, 2001, contract no. F19628-98-C-0067, p. 23, par. 3-3: "The reduced size and weight of a PEM fuel cell will reduce the airlift requirements for a deployed air expeditionary force."

55. "Observers say that by 2025, 48 countries will be severely short of water and half the people on earth will not have access to clean supplies. I can promise that if there is not sufficient water in our region . . . we shall doubtless face war." Paul Welsh, "Water Wars: Part I—The Middle East," http://news.bbc.co-uk/hi/english/world/middle_east/newsid_677000/677547.stm (accessed April 12, 2002).

56. Ohi, "Enhancing Strategic Management," 5.

57. See ibid., 8, par. 2-3, for the author's speculation about the first AEF fielded with fuel cells.

58. See Fellner briefing, charts 30–31, for information about future efficiencies of UAVs.

59. See M. J. Bradley and Associates, "Future Wheels: Interviews with 44 Global Experts on the Future of Fuel Cells for Transportation and Fuel Cell Infrastructure and a Fuel Cell Primer," November 1, 2000, submitted to Defense Advanced Research Projects Agency for agreement, no. NAVC 1099-PG030044, iv–v, for debate on which fuel is the most likely hydrogen-fuel source of the future.

60. See Fellner briefing, charts 30–31, for information about future efficiencies.

61. See Geohive, charts on energy statistics, http://www.geohive.com/charts (accessed April 6, 2002), for predictions concerning oil-supply locations through 2020.

62. See Wardell, "Dreams of the New Power Grid," 62, for quotation by Bos on fuel-cell costs futures.

63. See Fellner briefing, charts 25–31, for information about future capabilities.

64. See Ohi, "Enhancing Strategic Management," 11, for speculation by the author on where future cuts may occur.

65. See Tom Clancy's novel *The Bear and the Dragon* (New York: Berkley Books, 2000), 64–65, for speculation about finding a massive oil field in the Siberian plains.

66. See Janiszewski briefing for speculation about the future of propulsion technology.

67. David Mulholland, "Fuel Cells Could Enhance Military Capabilities," *Army Times* 59, no. 54 (June 7, 1999): 24.

68. Thomas and Zalbowitz, *Fuel Cells*, 26. The original *Hindenburg* did not explode just because of hydrogen gas. The dirigible's cotton fabric had been treated with acetate and nitrate (gunpowder); the combination was highly flammable.

69. "Fuel Cells," *U. S. Department of Energy, Energy Efficiency and Renewable Energy*, April 22, 2003, http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/stationary_power.html.

70. Michio Kaku, *Visions: How Science Will Revolutionize the 21st Century* (New York: Anchor Books, Doubleday, 1997), 323.

71. Thomas and Zalbowitz, *Fuel Cells*, 34.

Operational Control (OPCON)

Joint Publication (Pub) 1-02, *Department of Defense Dictionary of Military and Associated Terms,* December 17, 2003, defines *operational control* as "command authority that may be exercised by commanders at any echelon at or below the level of combatant command. Operational control is inherent in combatant command (command authority) and may be delegated within the command" (p. 385). Basically, OPCON is the foundation for command at all levels; it gives commanders the authority to organize commands and employ the necessary forces for assigning tasks, designating objectives, and giving authoritative direction for carrying out an operational mission. Additionally, OPCON allows commanders to direct all aspects of military operations and joint training for the purpose of conducting an assigned mission.

According to the definition in Joint Pub 1-02, combatant commanders and their designated representatives (subordinate commanders) have the express authority to exercise OPCON; neither the service chief nor the commander of the major command is in the loop. In order to accomplish an assigned mission effectively, the combatant commander will delegate OPCON of assigned (or attached) forces to the subordinate component commanders, who may include a joint force air and space component commander (JFACC) or a commander, Air Force forces (COMAFFOR). Regardless of the individual to whom the combatant commander relinquishes OPCON, the chain of command still goes up to the combatant commander.

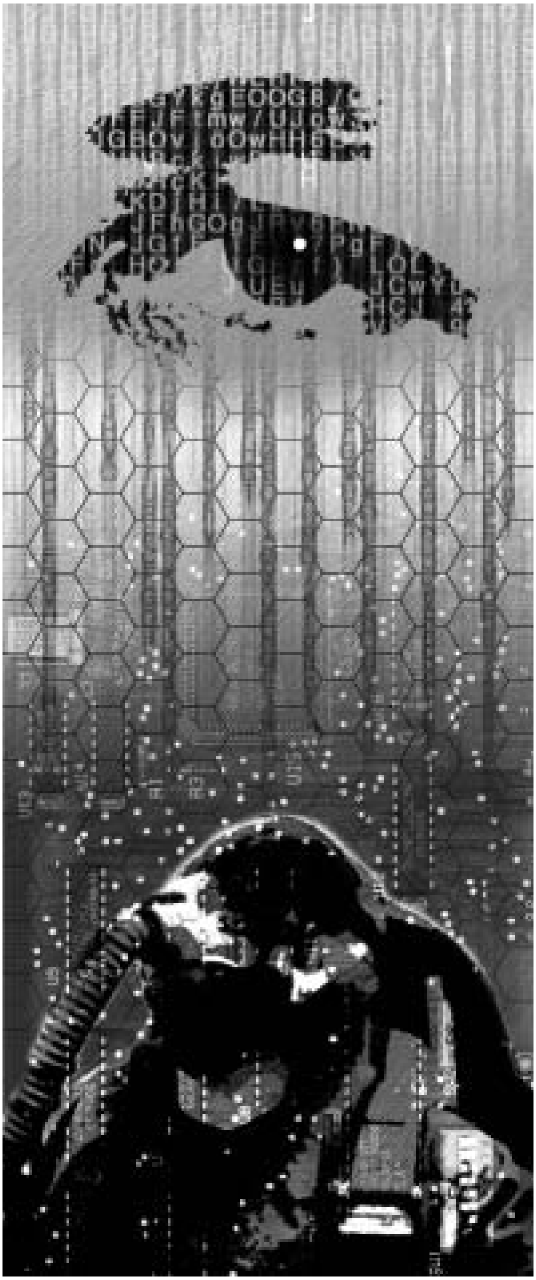
When a subordinate commander receives OPCON over joint forces, that control normally carries with it full authority to organize the commands and forces as he or she deems necessary for accomplishment of the operational mission. According to joint doctrine, this authority—granted by the president and secretary of defense—can provide for the transfer of OPCON from one combatant command to another. Such a transfer might occur because forces are often located in one area of responsibility (AOR) but are assigned to another command located elsewhere. In such situations, the national leaders decide which commander has OPCON of which forces. Normally, the geographic combatant commander has OPCON of these forces although there are exceptions to this rule. For example, forces that transit through a different AOR for a brief stint do not normally become part of that combatant commander's OPCON. Similarly, when forces actually bed down in one geographic command but are tasked to support a different combatant commander, the commander tasked with the mission retains OPCON.

Although the lines of distinction are somewhat hazy in these examples, the authority for OPCON traditionally remains with the commander tasked to achieve mission objectives rather than with the geographic commander to whom the forces are apportioned for planning purposes. The lines of distinction are further blurred when the original geographic commander temporarily surrenders OPCON of the apportioned forces but continues to have responsibility for providing logistical support, including food, water, bedding, air traffic control, and many other administrative functions. Although charged with logistically supporting the forces on his or her "base," the original commander does not necessarily have OPCON of them.

When it comes to preparing to fight wars and actually fighting them, we airmen believe in our air and space power doctrine. We use it to guide our employment of air and space assets in military operations. Based upon experience and historical examples, Air Force doctrine represents what we have come to understand. Although doctrine cannot provide a solution to every problematic situation, it does give us a starting point. We then have to utilize our own experiences and analyses of past situations in order to determine how best to handle the new ones. Air Force doctrine should reflect what has worked over the years, and for cases with which we have no experience, it should grow in order to capture and include such events. The key lies in determining which combatant commander is responsible for conducting the operational mission and ensuring that he or she has OPCON of those forces.

To Learn More . . .

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine,* November 17, 2003. https://www.doctrine.af.mil/library/doctrine/afdd1.pdf.



Military Applications of Information Technologies

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IGOR G. PLONISCH*

Editorial Abstract: The information age has increased the amount of data available to all commanders. Consequently, the Air Force Research Laboratory's Information Directorate seeks to transform military operations by developing systems that focus on unique Air Force requirements. The major thrusts include Global Awareness, Dynamic Planning and Execution, and the Global Information Enterprise. Supporting these developments are technology-focus areas, ranging from information exploitation, to air and space connectivity, to command and control.

AMONG OTHER REASONS, warfare constantly changes because advancements in technology lead to advancements in "the art of war." Today's information age has produced an explosion in the amount of information that is (or will be) available to commanders at all levels. Some observers believe that by 2010 "[air and space] planners will have an incredible amount of information about the target state. They'll never know everything, but they will detect orders of magnitude more about the enemy than in past wars. With this information, commanders will orchestrate operations with unprecedented fidelity and speed. Commanders will take advantage of revolutionary

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advances in information transfer, storage, recognition, and filtering to direct highly efficient, near-real-time attacks."[1] Some people believe that this scenario has already come to pass, laying the foundation for the transformation of warfare.

This transformation within the military services moves from classic platformcentric warfare to networkcentric warfare (NCW), the latter dealing with human and organizational behavior and based on new ways of thinking and applying those concepts to military operations.[2] It is defined as an information-superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, heightened tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization.[3] A conceptual view of NCW would highlight some of its major elements or building blocks (fig. 1). One may also envision a networkcentric view regarding command and control (C2) in the context of previous work done for C2 concepts (fig. 2).

Figure 1. Elements of networkcentric warfare. (This figure, as well as figures 3–20, is reprinted from USAF sources.)

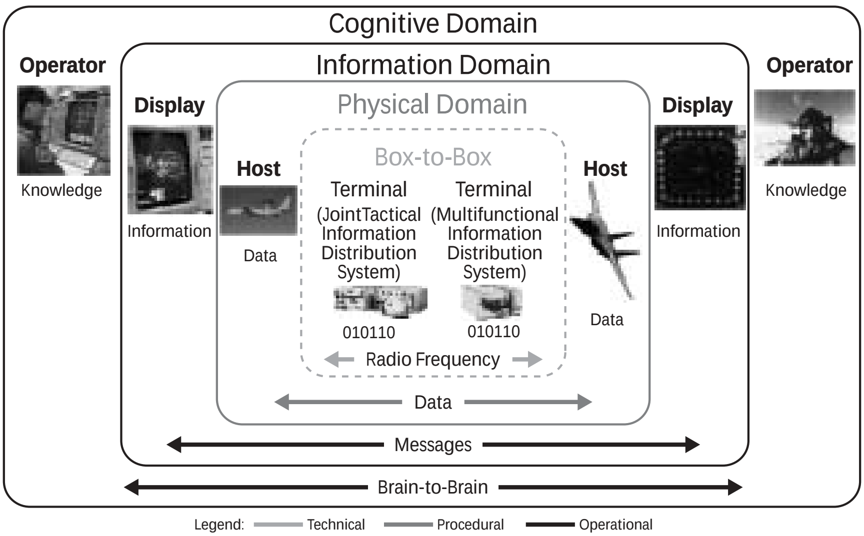

Figure 2. Domains of networkcentric warfare. (From briefing, Hanscom AFB, MA, subject: Information Technology for Networkcentric Warfare: An ESC [Electronic Systems Command] Integration Week Event, February 5–6, 2003.)

Critical advances in warfare-related information technology, the foundation of network-centric operations, have their roots in military laboratories, which provide a critical service to the military by transforming basic information technologies into war-fighting applications. Although the Air Force Command and Control and Intelligence, Surveillance, and Reconnaissance Center at Langley AFB, Virginia, has assumed the responsibility for the Air Force's command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) for more than half a century, the Air Force Research Laboratory's Information Directorate (AFRL/IF) in Rome, New York, has researched and developed technologies that have helped fuel the information revolution. The electronic computer, integrated circuit, storage and retrieval, and Internet, to cite but a few obvious examples, benefited from research performed or guided by scientists and engineers located in Rome. Moreover, AFRL technologies have found and continue to find their way into both military and commercial worlds where they, quite literally, transform operations, practices, and even ways of thinking (i.e., changes in doctrine).

Because *information* and *information technologies* often mean different things to different communities, it is important to understand the distinctions that might arise. The word *information* is commonly used to refer to various points on the information spectrum that convert data to knowledge.[4] Therefore, information has a different meaning, depending on the domain in which one operates. For example, David S. Alberts and others have identified three domains—physical, information, and cognitive—each of which describes and defines information differently.[5] However, the fundamental fact remains that information is the result of putting individual observations into some sort of meaningful context. Given this distinction, *information* is defined according to its application or, more specifically, the domain within which it will operate. Consequently, members of the commercial and academic communities treat information differently than do their counterparts in the military community.

Aside from the domain distinction just described, there are a number of reasons why the development of information technologies differs between the military and the industrial/academic communities. For example, the commercial market is driven by profit or return on investment, not by overall system performance. Additionally, in the commercial world, the end user of a new product has become the "beta tester." In a combat environment, where a fault discovery can literally sink a ship, this practice is unacceptable. Similarly, although a faulty design may cause numerous reboots per day on a commercial system, such recurring faults in a military system can cause injury or death. For example, during Operation Enduring Freedom, the system used by five US soldiers to direct an incoming smart weapon rebooted and, unbeknownst to them, inserted their current location instead of the target location into the system. Consequently, the weapon vectored onto their position instead of the selected target. The bottom line is that military applications demand higher performance at reduced cycle times and cost than do nonmilitary applications. Finally, commercial technologies are more computationally based (e.g., building better calculators, computers, etc.) while military applications are based more on supporting courses of action (e.g., campaign-planning assessment and effects-based operations [EBO]). Clearly, a significant need exists for military-specific information technology, even when such systems do not meet the profitability or return-on-investment criteria of the commercial sector. At this point the value of the AFRL/IF truly comes into play.

Research Efforts in Information Technology

The AFRL/IF seeks to transform military operations by developing information-systems science and technology that focus on unique Air Force requirements. By using commercial practices, it moves affordable capabilities to

Air Force ground, air, cyber, and space systems. Broad areas of investment in science and technology include upper-level information fusion, communications, EBO, collaboration environments, distributed-information infrastructures, modeling and simulation, intelligent agents, information assurance, information management, and intelligent information systems and databases. Successful outcomes from these areas provide affordable capability options required for Air Force information dominance and air and space superiority. To provide these capabilities, the AFRL/IF has three major thrusts—Global Awareness, Dynamic Planning and Execution, and the Global Information Enterprise—that receive support from seven technology-focus areas: information exploitation, information fusion and understanding, information management, advanced computing architectures, cyber operations, air and space connectivity, and C2.

Information Exploitation

Given the growing threat of global terrorism, the potential use and exploitation of readily available information technology by our adversaries make it imperative that the United States continue to invest in technologies for the protection and authentication of digital information systems for the military and homeland defense. Toward that end, the AFRL/IF conducts advanced research and development in the field of digital data-embedding technology. The directorate's work in such areas as information hiding, steganography, watermarking, steganalysis, and digital data forensics will greatly enhance war fighters' ability to exploit enemy systems while providing greater security to ensure that an adversary does not have access to US and allied systems.

Information Fusion and Understanding

What is going on? Who is the adversary? What is he up to? Such questions are being addressed in the emerging area of fusion 2+ or situational awareness (fig. 3). Over the past decade, the term *fusion* has become synonymous with tactical or battlespace awareness after hostilities have begun. As such, work has concentrated on identifying objects, tracking

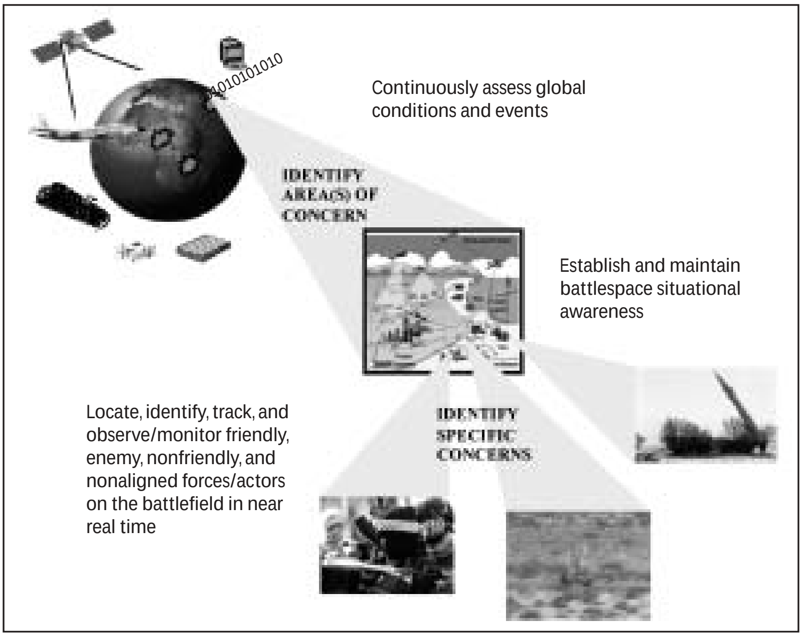

Figure 3. Fusion 2+

algorithms, and using multiple sources for reducing uncertainty and maximizing coverage. As more situations unfold throughout the world, smart, strategic decisions must be made *before* the deployment of limited assets. In order to assess adversarial intent and possible strategic impact, we have vastly broadened the scope of fusion to take into account strategic situational awareness and the information technology necessary to support it.

Air Force Space Command's strategic master plan states that "the first priority is to *protect* our vital national space systems so they'll be available to all warfighters when and where they are needed" (emphasis in original).[6] This protection also includes the ability to repair damage caused by a wide variety of anomalies that might affect space systems in orbit. As part of the Defense Advanced Research Projects Agency's (DARPA) Picosat program, the AFRL / IF launched the world's smallest satellite—the Micro Electro-Mechanical Systems-Based Picosatellite Inspector (MEPSI)—from the space shuttle in November 2002, thus laying the groundwork for an emerging onboard-protection and / or servicing capability for satellites. The InfoBot (fig. 4) is a robust onboard device that receives, processes, correlates, and distributes information reliably, unambiguously, and rapidly. This concept paves the way for numerous emerging capabilities, such as an onboard servicer or an onboard protector.

Space protection requires warning of possible threats (both natural and man-made) to allied space systems, receiving reports of possible attacks against satellites and US cross-cueing of other owners or operators, and directing forces to respond to a threat. To fulfill these needs, space systems must have onboard sensors to detect attacks and quickly report anomalies or suspicious events. The primary goal of these "battle bugs" (fig. 5) would be to provide a rapid-response capability to counteract impending threats that cannot be avoided by other conventional means (e.g., orbital maneuvering, shielding, etc.) in an inexpensive yet effective manner.

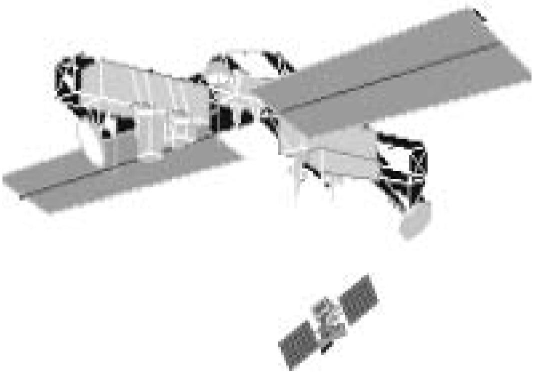

Figure 4. InfoBot

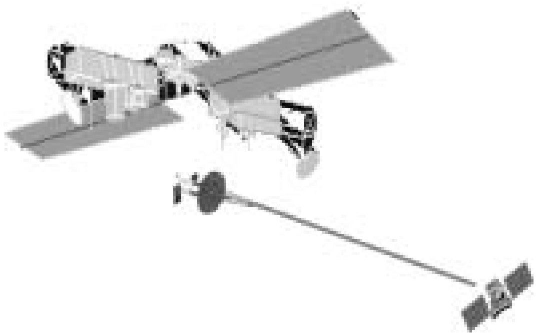

Figure 5. Space "battle bug"

Information Management

The essence of the joint battlespace infosphere (JBI) (fig. 6) consists of globally interoperable "information space" that integrates, aggregates, and intelligently disseminates relevant battlespace information to support effective decision making. The infosphere is part of a global combat-information-management system established to provide individual users at all levels of command with information tailored to their specific functional responsibilities. The JBI brings together all information necessary to support war fighters and their missions and allows them to obtain and integrate data from a wide variety of sources at the touch of a screen, to aggregate this information, and to distribute it in the appropriate form and degree of detail required by users at all levels. The JBI is a true system-of-systems in that it works for users at all echelons, from

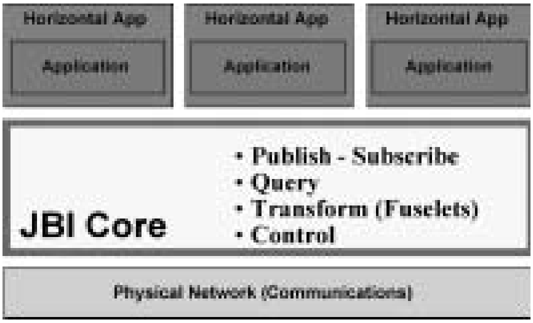

Figure 6. Infrastructure of joint battlespace infosphere

the remote battle-command center down to the soldier in the foxhole. It is distinct in organization, process, and usage from the communications infrastructure on which it rides and from the user-application systems that it serves.

The JBI is a "place," independent of fielded C4ISR systems, where information can be brought together. Past attempts to manage information have been system-based. That is, in developing a system (whether communications or user-application) to provide a given capability, developers made decisions on how to define, organize, manipulate, store, and transport information based on what was optimal for the particular system under development. These application-specific systems optimized information based on the storage and access needs of the system's software, data stores (databases), and intended user interface. Consequently, communication systems were optimized based on routing, bandwidth, throughput, and transfer speed. Management of information based on these optimizations has proven severely detrimental to interoperability—that is, the ability of systems to *exchange* and *use* information and services. The JBI acts as an "information layer" that harnesses the discipline of information management by eliminating the current "rigid-layered" information environment and replacing it with interoperable, consistently managed, widely available, secure information spaces that encourage dissemination of information to all who need it. The JBI will provide answers to numerous important questions: Where did the data come from? Who wants it? What is their priority? Is the data "good"? Can I trust it? Does the data need to be transformed, aggregated, or integrated with other information? Who may access it?

The multidomain network manager (MDNM) system (fig. 7) allows system administrators to monitor multiple security domains (e.g., US Only, Coalition, Unclassified) simultaneously on a single set of terminals. It will provide a network common-operating picture, hierarchical views of security domains, a secure boundary device for accessing net information, and a reduced operational footprint. Estimates indicate that the system will make possible a 10–25 percent savings in manpower, will keep costs low (less than $10,000 per installation), and will allow for multilevel attack detection of information warfare as well as response capability. Within an air and space operations center, for example, the MDNM would have the net effect of significantly reducing the number of system administrators required to monitor the various security domains around-the-clock, year-round and of collectively monitoring the system for adversarial intrusions.

An application programmer's interface, Java View (Jview) (fig. 8) is designed to reduce the time, cost, and effort associated with the creation of computer-visualization applications

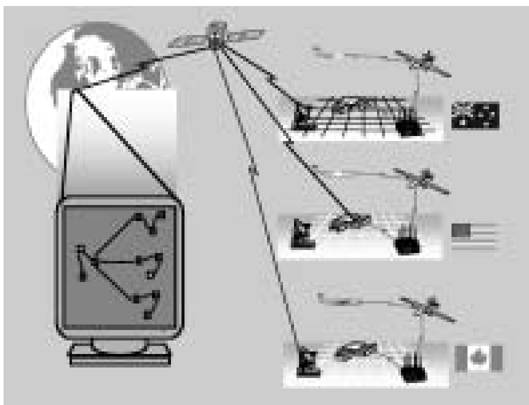

Figure 7. Multidomain network manager

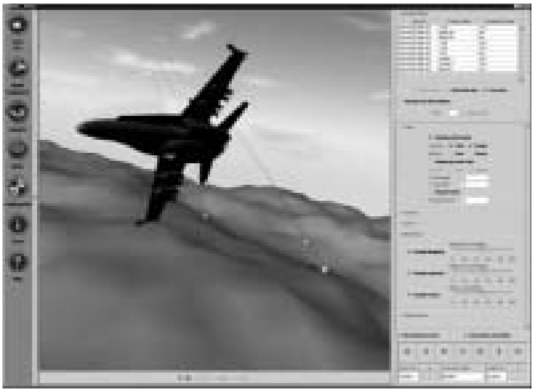

Figure 8. Jview

or the visualization interface of an application. Jview allows for the importing, displaying, and fusing of multiple simultaneous-information sources. What does this mean for the war fighter? Imagine having ultrahigh resolution within a flat screen in an F-15 or a B-2 or an eyepiece for the infantry soldier.

The new Department of Defense (DOD) doctrine for networkcentric operations requires the application of information and simulation technologies in order for the war fighter to function in a knowledgecentric universe that integrates air and space information. Mission commanders need to assimilate a tremendous amount of information, make decisions and responses quickly, and quantify the effects of those decisions in the face of uncertainty. AFRL's research on the distributed collaborative decision support (fig. 9) environment provides an *application-independent* collaboration

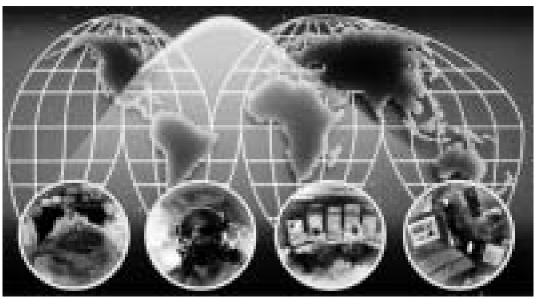

Figure 9. Distributed collaborative decision support

framework of integrated tools, information technologies, and adaptive collaboration services aimed at providing enhanced decision support, knowledge sharing, and resource-control capabilities. These technologies will allow geographically dispersed people, processes, and resources to work together more effectively and efficiently to create the products for distributed-defense enterprises of the future (e.g., collaborative battle management, crisis-response planning, and antiterrorism).

Timely information about enemy forces, friendly forces, and battlefield conditions is especially critical for combat aircrews whose battlefield situation changes rapidly. The common situational awareness (CSA) advanced-technology demonstration (fig. 10) is developing and demonstrating the onboard information-system architecture needed to support task-saturated crews by processing, selecting, and displaying available information. The CSA program, targeted at multiple special-operations-forces mission and aircraft platforms, will integrate information from onboard systems and exploit off-board intelligence databases and imagery products to provide a consistent battlespace picture to the aircrew. The CSA design contains three key elements: connectivity, integrated modular architecture, and a crew/system interface.

Advanced Computing Architectures

Growth of information technology in the twenty-first century will be driven by ad-

Figure 10. Common situational awareness

vanced computing technology brought about through the development and implementation of information-processing paradigms that are novel by today's standards. Advances in information technology will provide tremendous benefits for war fighters who not only face the enemy on the field, but also struggle to comprehend the overwhelming amount of data coming at them from numerous sources. Future information systems will include biomolecular and quantum computing subsystems (fig. 11) that incorporate data-storage and processing mechanisms with density and performance metrics, such as power and speed, far beyond current state-of-the-art silicon technologies. These information systems are likely to be hybrid systems consisting of biomolecular/silicon, quantum/silicon, or biomolecular/quantum/silicon computing architectures. They will be able to process information faster as well as acquire new attributes that will enable progress toward even faster, more intelligent computing systems.

Current space systems utilize 1970s and 1980s technology in the form of 286/386/486/586 microprocessors. However, tying C2 systems, sensors, and weapons via "horizontal integration" requires the ability to rapidly process new as well as previously acquired raw imagery data. A diverse, distributed community of intelligence analysts and battlefield decision makers needs this capability so its members can take appropriate actions based upon these analyses. AFRL/IF is working with its sister directorates—Sensors (AFRL/SN)

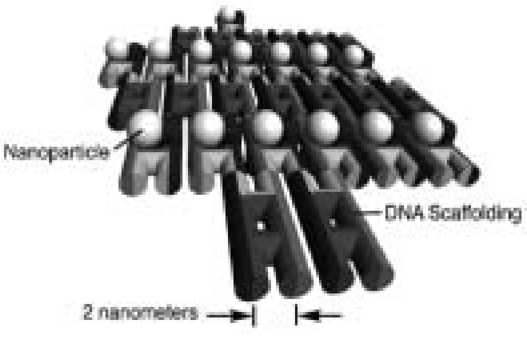

Figure 11. Biomolecular and quantum computing

and Space Vehicles (AFRL/VS)—on the next-generation space computer (fig. 12). Imagine an onboard Cray-like supercomputer that would provide enough processing power so that up to 50 percent of a satellite's mission ground station could be housed in a single spacecraft. This space computer will enhance a satellite's processing capability from millions (10^6) of operations per second to a trillion (10^{12}) operations per second in 2006. Mission ground stations can take advantage of up to a quadrillion (10^{15}) operations per second in 2010. Such capability carries with it significant advantages within the space community: reduction in footprint, significant reduction in operation-and-maintenance costs, and the ability to directly view, process, exploit, and disseminate information throughout a theater of operations without reaching back to a fixed mission ground station.

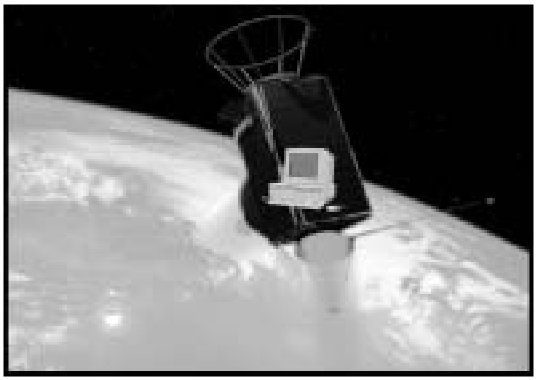

Figure 12. Next-generation space computer

Cyber Operations

Software intelligent agents make possible the controlling and "patrolling" of cyberspace. These encapsulated software entities have their own identity, state, behavior, thread of control, and ability to interact and communicate with other entities, including people, other agents, and legacy systems. Essentially "cybervehicles," often referred to as "infocraft" (fig. 13), they would operate in the cyber domain similar to the way air and space vehicles operate in the atmosphere.

Figure 13. Infocraft

Air and Space Connectivity

Achieving a completely secure, noninterceptable operational environment requires the secure transfer of information using channels dominated by quantum effects—that is, quantum key distribution (QKD) (fig. 14). In most cases, quantum noise is key to developing a communications channel, but recent work employing quantum-limiting behavior independent of noise is making a major contribution to information assurance. In conjunction with the Air Force Office of Scientific Research, AFRL / IF is currently addressing three major problems that inhibit the establishment of a quantum channel: signal-to-noise ratio, channel control, and maintenance of usable data rates.

The timely establishment of communications-network connectivity is vital to the success and survival of US forces in modern-warfare environments. Recent conflicts have proven the need for rapid deployment and quick reaction to fast-changing scenarios. Effective and responsive decision making becomes impossible without adequate and reliable local (e.g., handheld radio, wireline and wireless data networks, and point-to-point microwave) and long-haul (e.g., high-frequency or satellite) communications both within and outside the battlespace. The adaptation of commercial-radio, local-area-network (LAN) technology now makes possible the swift establishment of high-speed Internet-protocol-based data networks in forward locations. The vehicle-mounted mobile satellite communications

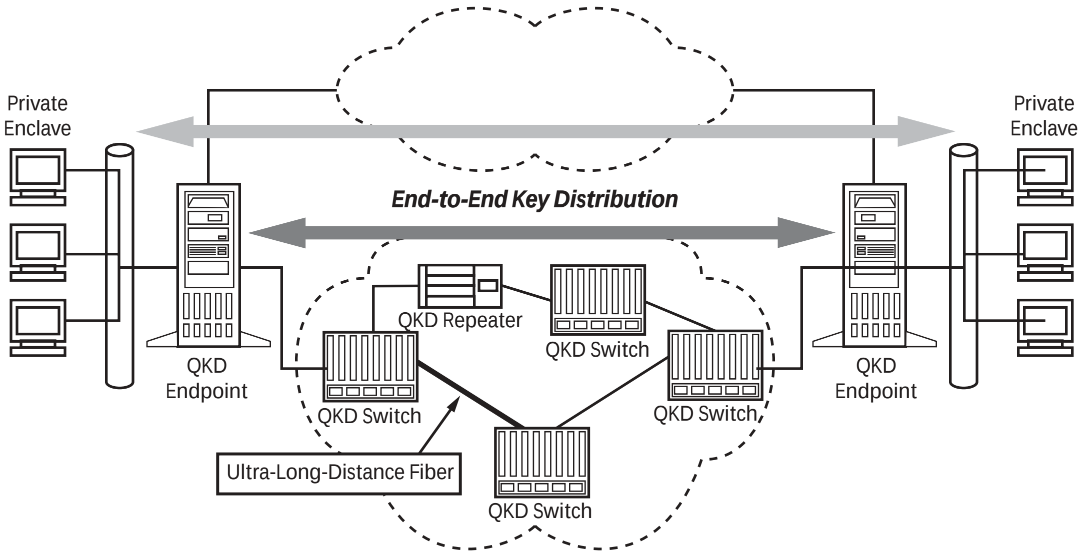

Figure 14. Quantum key distribution

(SATCOM) terminal (fig. 15) is attached to an Internet protocol router that will provide Internet connectivity for a wireless LAN comprised of laptop computers in separate moving vehicles following the gateway vehicle. Over the past two years, several activities, such as the Warrior and Global Patriot exercises at Fort Drum, New York, have included demonstrations of AFRL's mobile SATCOM terminal.

Figure 15. Ka-band (satellite-based broadband) mobile SATCOM on the move

Industry-standard commercial wireless LANs, such as the Institute of Electrical and Electronics Engineers (IEEE) 802.11 family, create an important opportunity for the military to leverage widely available, low-cost technology in applications that are difficult, costly, or impossible to realize with standard wired networks or traditional military-communications systems (fig. 16). These hugely successful standards provide link speeds of up to 54 million bytes per second over distances ranging from hundreds of meters to tens of kilometers, using equipment that seamlessly integrates with the vast majority of commercial data-processing equipment currently used by our forces. In spite of the great potential of this technology, risks abound with its use since the networks operate in unlicensed frequency bands, are easily jammed, lack mutual authentication, use insecure management protocols, employ weak and flawed encryption algorithms, are easily monitored, and are void of intrusion-detection systems, just to name a few shortcomings.

Figure 16. Enhanced commercial wireless network for military operations

At first glance, this technology seems completely inappropriate for use in critical, high-assurance environments such as those surrounding most military operations. Fortunately, it is possible to reduce or eliminate most of the risks involved in using networks based on IEEE 802.11. One such solution utilizes AFRL's protected tactical access point, the core of which is an IEEE 802.11b basic service set that uses a commercially available access point as its centerpiece. Because client stations are also based on unmodified IEEE 802.11b hardware, one thus achieves maximum leverage of low-cost commercial technology. Several different approaches and technologies are combined to form a system in order to mitigate inherent risks and increase information assurance on this network. Also, higher-layer mechanisms such as virtual private networks, firewalls, address filtering, strong encryption, and mutual authentication supplement these bottom-layer safeguards to provide a comprehensive information-assurance solution based on defense-in-depth strategies.

The Advanced Transmission Languages and Allocation of New Technologies for International Communications and the Proliferation of Allied Waveforms (ATLANTIC PAW) project (fig. 17) is an international effort among the United States, Germany, France, and the United Kingdom to enable interoperability of multinational wireless-communications assets. The program seeks to demonstrate portability of radio-waveform software onto independent radio-hardware platforms. The approach to achieving waveform-software transportability entails the cooperative formulation of a waveform description language to capture radio-waveform functionality and a waveform-development environment to translate this description into operational radio-waveform software.

Airborne tactical data links, a key element of our C2 structure, are essential to the ability of our fighting forces to perform their mission and survive. Transforming war-fighter capabilities by exploiting networkcentric technologies requires a dramatic and affordable overhaul of this capability. The tactical targeting network technology (TTNT) program, funded by DARPA, will develop, evaluate, and demonstrate rapidly reconfigurable, affordable, robust, interoperable, and evolvable communications technologies specifically designed to support emerging networked targeting applications devised to keep fleeting targets at risk. Laboratory and initial flight testing have already indicated that the TTNT design can exceed its goals.

US space missions and services such as on-demand space-launch control and on-orbit space-asset servicing require on-demand access to the satellite to conduct real-time operations. The main bottlenecks of space support include limits and constraints on the availability, operability, and flexibility of reflector antennas that provide links between space assets and space-operation centers on the ground. A novel geodesic-dome, phased-array antenna (fig. 18) under development—enabled by low-cost, innovative transmit / receive module technology—will alleviate the bottleneck. Furthermore, it will meet Air Force transformation needs through new capabilities in multiband, simultaneous access; programmable multifunctionality; and integrated mission operation.

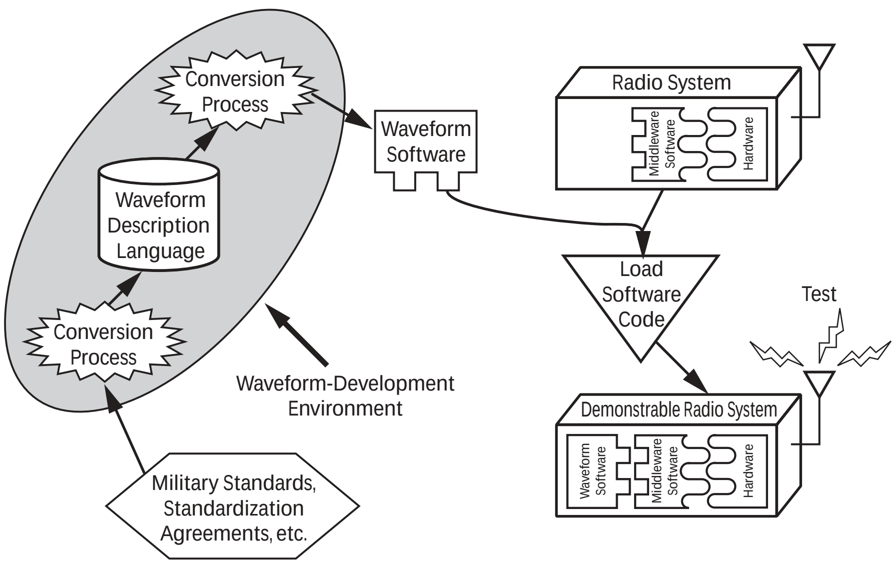

Figure 17. ATLANTIC PAW

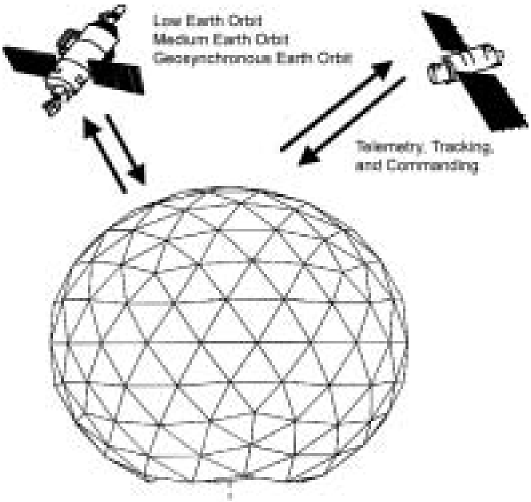

Figure 18. Geodesic-dome, phased-array antenna

Command and Control

The Air Force's commitment to meeting the challenges of tomorrow resides within many of its transformation activities. To frame these activities, the service is adopting an effects-based mind-set to air and space maneuver and warfare. Air and space strategy describes the synchronization in time and space of air and space power to achieve desired objectives. Continuing this logic, EBO orients air and space power and represents a means of articulating the joint force air and space component commander's air and space strategy to achieve these high-level objectives using either lethal or nonlethal means. This implies leveraging air and space power's asymmetric advantages to create the desired effects at the right place at the right time. The AFRL has initiated an advanced technology demonstration (ATD) to develop new capabilities for implementing EBO. Current processes for planning, executing, and assessing military operations utilize target- and objectives-based approaches that lack dynamic campaign assessment and fail to address timing considerations, direct and indirect levels of effect, and automated target-system analysis during strategy development. The AFRL/IF's EBO ATD focuses on building campaign-assessment and strategy-development tools to fill existing voids.

For years the Air Force has struggled to find an approach to campaign assessment more general than the "rollup" of bomb damage assessment. The causal analysis tool (CAT), designed to perform dynamic air-campaign assessment under general conditions of uncertainty, utilizes Bayesian analysis (a statistical approach that takes prior information into account in the determination of probabilities) of uncertain temporal, causal models without requiring analysts to have specialized mathematical knowledge. CAT emphasizes support for modeling such (uncertain) causal notions as synergy, necessity, and sufficiency. Developed as a tool for the analysis of EBO-style air campaign plans, CAT is a critical piece of the strategy-development tool that allows for assessment of the effects-based plan from the plan-authoring component.

According to Lt Gen William Wallace of the Army V Corps during Operation Iraqi Freedom, "The enemy we're fighting is different from the one we'd war-gamed against,"[7] a statement that offers clear evidence of the need to pursue enhanced methods of war gaming throughout the DOD. In this era of EBO and transformation, war games must evolve accordingly to foster an adequate portrayal not only of US doctrine and systems, but also those of the enemy. War games must be adaptive, agile, and without bias. AFRL/IF is taking initial, collaborative steps to develop this new method of war gaming with the goal of both simulating victory and making it happen—faster and with fewer casualties and less collateral damage. To accomplish these goals, AFRL/IF is developing a capability for a third-generation war game (3GWG). By incorporating three additional, crucial thrusts—decision cycles, human factors, and operational effects—the 3GWG augments second-generation war games that successfully model attrition, movement, and logistics (fig. 19). Additionally, 3GWGs will help educate decision makers by assisting them in making better decisions.

The military commander must be able to live in the future, understanding the impact

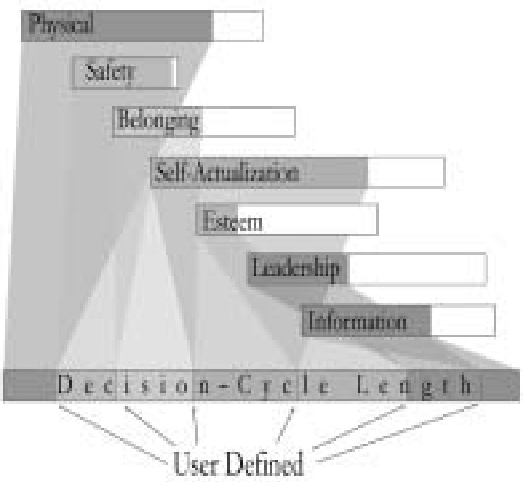

Figure 19. War games for the next century of war fighters

of decisions made today on the battlespace of tomorrow. The more senior the commander, the farther into the future he or she must be able to see. At all levels, commanders continually make decisions and decide upon courses of action, based on their current understanding of the world and their ability to forecast the outcomes of actions under consideration. This ability typically emerges after years of training, extensive combat experience, and a rigorous selection process. However, even experienced tacticians can consider only two or three possible courses of action for all but the simplest situations. To achieve predictive battlespace awareness (PBA), one must address numerous, complex technical issues; additionally, for the Air Force, PBA must deal with changes in culture, organization, architecture, and technology. A key ingredient of PBA includes providing a simulation capability so the commander can better visualize the potential futures resulting from military decisions. This simulation capability can take on many forms, but it has been dubbed the joint synthetic battlespace (fig. 20). The next five to seven years will witness the emergence of technology that will provide a real-world, synchronized simulation capability for the war fighter.

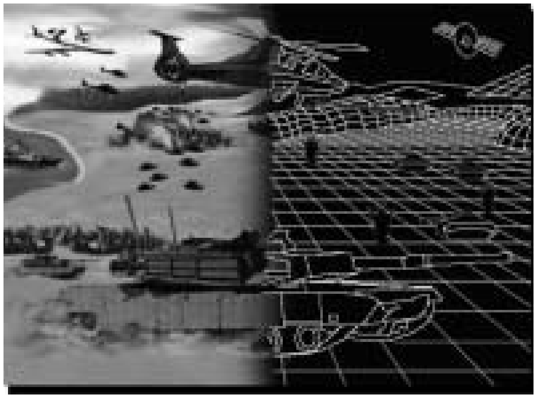

Figure 20. Joint synthetic battlespace

Summary

Not only has information technology improved commanders' situational awareness, but also it has increased the complexity of the decision-making environment. Successful outcomes from these areas provide affordable capability options that the Air Force requires for information dominance and air and space superiority. The Air Force Research Laboratory's Information Directorate remains on the cutting edge of transforming information technologies into war-fighting capabilities. The AFRL/IF is committed to the transitioning of science and technology that provide critical war-fighting capabilities in such areas as signals, imagery, measurements intelligence, information fusion, information management, advanced computing, cyber operations, and C2—the critical information-technology areas that will support the war fighter of the future. The directorate is also committed to developing information dominance that supports global awareness by moving relevant information through the predominantly commercial-based Global Information Enterprise environment for the dynamic planning and execution of the commander's battle plan. □

Notes

1. Jeffery R. Barnett, *Future War: An Assessment of Aerospace Campaigns in 2010* (Maxwell AFB, AL: Air University Press, January 1996), xx–xxi.

2. The transition from platformcentric to networkcentric is but the beginning of a transformation to higher levels of warfare. The authors believe that the next evolutionary steps will move from informationcentric to knowledgecentric warfare.

3. David S. Alberts, John J. Garstka, and Fredrick P. Stein, *Network Centric Warfare: Developing and Leveraging Information Superiority*, 2d ed. (Washington, DC: C4ISR Cooperative Research Program [CCRP], February 2000), 2.

4. David S. Alberts et al., *Understanding Information Age Warfare* (August 2001; repr., Washington, DC: CCRP, July 2002), 16, http://www.iwar.org.uk/iwar/resources/ccrp/UIAW.pdf.

5. Ibid., 16–29.

6. *United States Space Command, Long Range Plan, April 1998*, chap. 5, "Control of Space," http://www.fas.org/spp/military/docops/usspac/lrp/ch05a.htm.

7. Julian Borger, Luke Harding, and Richard Norton-Taylor, "Longer War Is Likely, Says US General," *Guardian Unlimited*, March 28, 2003, http://www.guardian.co.uk/Iraq/Story/0,2763,924497,00.html (accessed January 19, 2004).

The Joint Personnel Recovery Coordination Center

The Next Step in Joint Integration

Maj Eric Braganca, USAF

Editorial Abstract: At every level of the Department of Defense, personnel recovery is a priority mission, a fact reflecting the high value that American warriors place on their fellow soldiers, sailors, airmen, and marines. Each service has devoted thought, personnel, and resources to this critical mission. Improving personnel recovery across the services requires that commanders carry out all tasks effectively and efficiently. To improve the integration of personnel recovery, joint force commanders should create a new entity—the joint personnel recovery coordination center.

PERSONNEL RECOVERY (PR) has improved dramatically in the last 15 years.[1] At every level of the Department of Defense, PR is a priority mission, a fact reflecting the high value that American warriors place on their fellow soldiers, sailors, airmen, and marines. Each service has devoted personnel, thought, and resources to this critical mission area in order to improve the joint force's overall capability and interoperability. Especially in the years since Operation Desert Storm, the military has purchased better radios, as well as more sophisticated surveillance and reconnaissance equipment, and has improved training—all with an eye toward carrying out "one of the highest priorities of the Department of Defense."[2] The success of this approach has saved lives in battlefields since the war with Iraq in 1991—from the high-profile rescues of downed F-117 and F-16 pilots over Serbia, to the less renowned but more numerous missions in Afghanistan, and to such notable successes as the recovery of Pfc Jessica Lynch during Operation Iraqi Freedom. Despite this enviable track record, we still have an obligation to look to the future and develop new methods for tomorrow's battlefield, which may require even more PR.

Improving our PR capability requires that commanders understand the tasks involved, delegate them appropriately, and leverage the personal and organizational creativity latent in the force to carry out those tasks in the most effective and efficient way possible. Of course, any changes to the current system must produce significant improvement and remain successful, yet be financially realistic.

Proposal

In an effort to improve PR integration, joint force commanders (JFC) should create a new entity in their staffs—the joint personnel recovery coordination center (JPRCC)—to replace the joint search and rescue center (JSRC).[3] By working for the JFC, the JPRCC will intensify its focus on operational warfare.[4] This arrangement will also allow components—particularly the air component—to better direct their attention to tactical PR efforts and will open up new possibilities for enhanced joint integration, especially by using more flexible command relationships. Furthermore, none of these changes will come at the expense of recent improvements.

Current joint doctrine offers JFCs the option to retain the JSRC at their headquarters or delegate it to a component commander (fig. 1).[5] In practice, JFCs have routinely chosen to delegate this responsibility to their air component. But retaining the JSRC at the JFC level has the potential to improve PR dramatically by better monitoring and coordinating all means of recovery, such as combat search and rescue (CSAR), nonconventional assisted recovery, and so forth.[6] This new location allows a more holistic view of PR and has spawned a new name, JPRCC, which indicates a broader view of the mission—specifically, less tactical control and more operational integration. Joint PR doctrine, now in draft, should sanction the addition of the JPRCC to

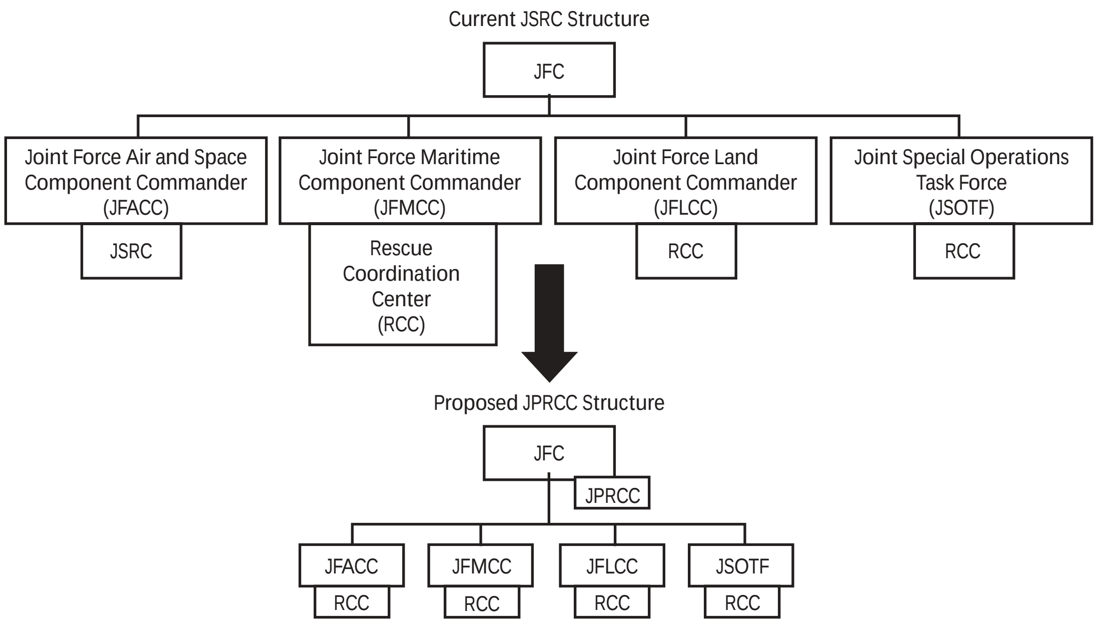

Figure 1. Current and proposed personnel recovery structure

the JFC's staff and delineate the risks associated with delegating it to a component.[7]

Creating a JPRCC at the JFC's headquarters will not decrease current tactical successes but will open up new avenues for operational integration. Retaining traditional CSAR activities at the component level, such as the joint force air and space component commander's (JFACC) rescue coordination center (RCC), will significantly broaden PR options without slowing responsiveness or agility. It will maintain the current record of successful missions and increase joint awareness and involvement in PR. A new JPRCC will not require significant funding, nor will it substantially increase the number of personnel for the JFC or the components. Although it will add some personnel to the JFC's headquarters, the warfighting components will continue to function as they have, retaining the vast majority of their manning.[8] More importantly, this new concept will not alter PR/CSAR tactics, techniques, and procedures (TTP) for any service.[9] It will, however, require some new approaches to operational thinking—demands that the small groups of military PR schools can meet. Such new approaches can easily become part of Joint Chiefs of Staff and theater exercises, most of which already include PR events.[10]

Improved Operational Focus

The JSRC, routinely delegated to the JFACC, has become the focal point for all PR efforts by "plan[ning], coordinat[ing], and execut[ing] joint search and rescue [SAR] and CSAR operations; and . . . integrat[ing] CSAR operations with other evasion, escape and recovery operations within the geographical area assigned to the joint force."[11] However, because the JSRC combines the tactical focus of the JFACC's RCC and the operational focus of the JFC, its efforts are divided between tactical execution and operational planning (fig. 2). This dual-hatted function has forced JSRCs to concentrate on essential tactical tasks and accept risk by losing focus on other means of recovery. Current JSRCs at the JFACC level devote much effort to developing and publishing special instructions and communicating with components, as well as monitoring and (frequently) directing PR incidents. Maintaining control over PR tactical operations—something that a component RCC must do—hampers JSRCs. But a JPRCC will unleash new potential by developing PR-specific joint intelligence preparation of the battlespace (JIPB), allowing the JPRCC to generate a broad threat-decision matrix; integrating PR themes into the JFC's psychological operations (PSYOP); including nontraditional military forces in planning; improving links to interagency and nonconventional forces; and harnessing more flexible command relationships. Relieved of the RCC responsibility of controlling tactical operations (retained by component commanders), JPRCCs could concentrate more effectively on these operational links, thus significantly improving PR efforts by more effectively leveraging national power for this high-priority mission.

PR planners have struggled with recommending when and how to execute PR missions. One of the JSRC's current combat-operations tasks—a PR decision matrix, tailored to the current threat—is designed to aid PR decision makers in this regard.[12] JSRCs typically have no planners since they are usually located in the combat-operations section of the air and space operations center and are prepared to tactically control a PR

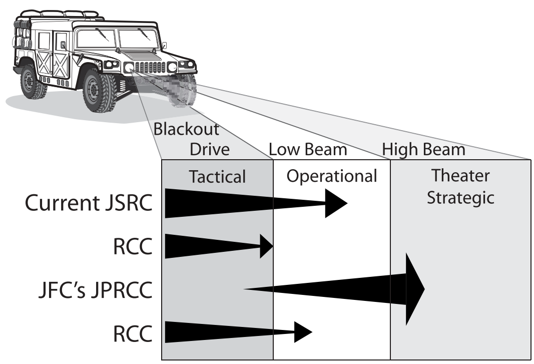

Figure 2. Focus of the JPRCC

mission. Unable to look beyond current air tasking orders due to the demands of short-range planning meetings, JSRCs must focus on the current fight. A JPRCC, however, could more readily focus on long-term issues.

PSYOP and information operations in general allow war fighters to inform enemy forces and populations about friendly actions—a capability particularly important to PR missions in which isolated or distressed persons must evade the enemy in either hostile or neutral territory. PSYOP can convince people in these areas not to interfere in recovery missions. In fact, under favorable circumstances, PSYOP may be able to persuade neutral parties to assist isolated personnel and return them to friendly control. Since the JFC usually develops and/or approves operational PSYOP themes, having the JPRCC closer to this planning process will invariably improve the effectiveness of PR. Integrating PSYOP into a comprehensive PR plan requires time—which tactically focused JSRCs don't have.

Integration with nontraditional military forces, such as Civil Affairs (CA), could also increase our PR efforts.[13] Although some people think that CA personnel arrive only when the fighting is over to build bridges, repair infrastructure, and coordinate humanitarian-relief operations, in reality they operate side by side with combat forces as decisive operations and nation-building phases merge. Central Command established CA in Afghanistan and Iraq long before combat operations ended; moreover, US forces are simultaneously conducting nation-building and antiterrorist operations. Because CA personnel gain local knowledge in their day-to-day dealings with the population, they can provide key insights to PR planners and executors. Their routine contacts with many nongovernmental organizations further broaden their knowledge base. Although it is unrealistic for these forces to participate actively in combat-rescue efforts, they do lend valuable guidance to a JPRCC's threat assessment or evasion policy. Afghanistan and Iraq aside, not all military operations are combat operations. Frequently, US forces provide humanitarian relief in areas overwhelmed by natural disasters or internal strife, as occurred numerous times in Africa in the late 1990s (e.g., Rwanda and Mozambique). But this change offers the JPRCC opportunities beyond the links to military forces.

The many boards, bureaus, cells, and offices in a JFC headquarters—all of which fuse various elements of national power—frequently are the first places where diplomatic, information, and economic expertise mix with military forces to achieve strategic or campaign goals.[14] An operationally focused JPRCC will easily tap into these rich sources of information to provide war fighters more tools and options for the entire force. Since PR includes concerns about prisoners of war (POW), having access to an interagency working group makes available the diplomatic arm of US power, highlighting the need to account and care for US/allied POWs and personnel missing in action. The Joint Staff frequently deploys national intelligence support teams to JFC headquarters to assist in harnessing the vast capability of the various intelligence agencies.[15] As with the interagency working group, a JPRCC located above the components—and thus having ready access to these teams—will be able to leverage its power.

Better Tactical Focus

Similarly, JFACC staffs will find the change an improvement over the current method. As already mentioned, these personnel struggle with dual tasking, serving as the component RCC and operational JSRC throughout the joint operations area.[16] This situation works due to the incredible effort by the dedicated men and women who make up these staffs. We no longer have to require so much work from so few people or rely on the good graces that have recently made our PR efforts successful, especially when the price of greater capability is relatively low.

In the years preceding and immediately following Desert Storm, PR predominantly meant rescuing downed aircrews (CSAR to most people), so it made great sense to place the JSRC with the air component. However, in recent conflicts, ground troops operating in rear areas or serving as border guards on a peacekeeping mission, for example, are vulnerable. CSAR procedures, designed and tested for and by aviators, do not always work because ground forces face different realities, such as phase lines and surface boundaries, which airmen have difficulty understanding. JSRCs, used to transmitting information rapidly via the Secret Internet Protocol Router Network to secure air bases and to airmen with a common vision of the battlespace, now struggle to understand land warfare and infantrymen. A JPRCC, with representatives from all the components, can establish procedures for the entire joint force, allowing the JFACC to concentrate on PR for airmen and not on the unfamiliar field of land warfare.[17]

Current staffs struggle with many of the less-obvious tasks involved in PR, routinely overlooking repatriation, for example. What does one do with a survivor once friendly forces regain control? If the survivor is a JFACC pilot, the JFACC's RCC/JSRC has complete control over the repatriation process as well as the survivor. However, if the survivor is from another component, as were the three Army soldiers captured in Kosovo in 1999, the situation becomes much more difficult. Under a JPRCC, the JFACC will no longer be responsible for enforcing policies on a sister component. Likewise, the other components will view PR as part of their joint responsibilities and no longer solely as their contribution to the JFACC's process. If the JFC owns the process (created with input from all components) through the JPRCC, then no component can circumvent it.

The shift in responsibility required by this approach will make the change transparent to most war fighters. The JPRCC will not command and control but will plan and integrate the joint force, leaving tactical tasks to the war-fighting components. During a PR event, the JPRCC will monitor to maintain situational awareness in the event the affected component requires assistance or is incapable of performing PR tasks. In such a case, the JPRCC—acting as the JFC's agent and with his or her guidance—will act as broker, nominating a supported component and, with JFC approval, designating other components to support. Tactical control of the PR event will remain with the war-fighting component, as it is now. This will assure continued success and, by limiting the JPRCC's role in tactical operations, will prevent undue influence on service-specific TTP. Such a scenario offers a win-win situation for JFACC staffs—the JFACC retains the air-component RCC but is relieved of the responsibility to integrate other elements of military power not directly related to airpower. However, there are even greater advantages to creating the JPRCC.

Better Joint-Force Integration

The single greatest improvement from such a move is the ability to use more flexible command relationships. Currently, most JSRCs assume tactical control (TACON) of any elements conducting PR missions.[18] Although this relationship has worked for air-dominant PR, TACON is usually not clearly defined (e.g., when does it begin and end?). Other component commanders have been highly reluctant to hand over control of their assets to the JSRC when they have their own war-fighting missions to carry out, and they fear being forced to use another component's TTP. TACON also creates more problems during the fusion of warfare across the land, air, and sea mediums. But establishing a JPRCC at JFC headquarters and using the more flexible command relationship of support could eliminate both of these concerns.[19]

For more than 10 years, JFACCs have taken TACON of the other components' air sorties to incorporate them into a seamless air campaign. This action works because JFACC staffs have a great capacity to integrate this airpower. JSRCs have translated this concept to PR because that mission has frequently meant the recovery of downed pilots through the use of airpower alone. Since those pilots belonged to the JFACC, TACON was the right command relationship. Recent contingencies have challenged this paradigm, however, and have opened gaps in the TACON approach. For example, the number and reach of special operations forces (SOF) introduce a more complex battlefield with small teams throughout, representing unique PR challenges and requirements. A special-operations commander with a team in distress should be able to tap into the JSRC for expertise without automatically passing control of the mission to another component. When a JFACC pilot is the survivor, the JFACC commands that individual, who is unfamiliar with the environment and requires detailed direction for recovery. But a SOF team has dramatically greater situational awareness and the capability to make decisions favorable to its recovery. SOF commanders may require limited assistance (e.g., close air support [CAS] and intelligence, surveillance, and reconnaissance [ISR]) to recover their teams but have frequently been forced to relinquish control of their forces (air and ground) to leverage the support of another component. This requirement hasn't caused mission failure in recent years, but the resultant friction has significantly delayed missions while the SOF component and JSRC resolved issues.[20] A JPRCC's designation of one component as the supported command and the others as supporting elements will eliminate this problem. Regardless of which is supported, none will lose tactical control of assets. The supported commander will dictate the priority, timing, and effects while the supporting commander retains control of TTP to fulfill the mission.

This principle's greatest test comes as conventional forces operate in less linear ways. For example, in Millennium Challenge 02—an experiment by Joint Forces Command—conventional forces leaped over pockets of resistance to attack key nodes in order to achieve the desired effects.[21] This tactic created a nonlinear battlefield with pockets of friendly forces—similar to the fight in Afghanistan and Iraq today. An air-component JSRC that tries to assume TACON of non-JFACC forces for PR is frequently unaware of the overall campaign and of the impact its action will have on the surface fight.[22]

Thus, commanders are reluctant to pass TACON to other components because the latter do not understand those forces. Typically, Air Force and Navy airpower remains under the control of a single airman, who can exploit their similarities. Frequently, Army and Marine Corps ground power comes under the control of a single ground commander, who can synchronize their operations. These forces can conduct air-ground operations without passing TACON between the air and ground components because they recognize their common efforts and their dissimilar abilities. For instance, air commanders provide CAS to ground commanders to help them achieve ground objectives without passing TACON of the aircraft. Air commanders develop specialized command and control elements to provide this support while retaining control of their assets. This practice works since ground commanders have little or no ability to control airpower. The same sort of thinking should apply to PR.

Changing PR command and control to "support" will produce a shift in favor of the rest of joint war fighting. Rather than a radical change, this is really an example of the broader joint approach. A JPRCC above the components will be able to effectively use this technique, delegated by the JFC, because of its ability to view the broader implications of joint warfare. This capacity to improve the command and control of PR offers the greatest potential to increase capability without additional forces or cost. Simply allowing other component commanders to retain control of their assets while they direct or assist PR operations will dramatically increase their willingness to participate.

Cost of Training

Since JFCs and component commanders must incorporate this shift into their battlestaff training, any attendant costs would be realized there. But these are recurring events, both within the services and jointly, so little expense is involved. This change will not levy any new training requirements or tactical training but, hopefully, will improve the quality of PR training. All that's needed is a mental shift to align more closely with the rest of joint war fighting.

Conclusion

American values demand that PR remain a high-priority mission. So the challenge for PR planners and operators lies in creating a system that harnesses the massive talents of our military without setting aside so much power that doing so would impede the primary mission, whatever that might be. Creating a JPRCC at the JFC's headquarters helps solve this problem.

Such an arrangement will provide better focus on the core functions of integration. It offers relief from tactical operations—true for all boards, bureaus, cells, and offices—allowing concentration on operational issues such as a PR-specific JIPB, including both ground power and airpower. A JFC-level JPRCC will be better positioned to integrate with nonconventional elements of US power such as PSYOP, CA (where appropriate), and interagency groups. And since a JPRCC will not assume control of tactical operations, the war-fighting components will retain authority over their own forces or TTPs, thus enhancing their chances of success. Without adding funding or forces, PR will lend perspective and reach to the joint battlefield, but the greatest improvement lies in the shift toward true joint war fighting.

Using more flexible and responsive command relationships will better integrate the components into a truly joint PR operation. Many components fear the loss of control and capability when the only option calls for passing TACON of key assets to another component. Creation of a JPRCC and elimination of any tactical role might cause the future of PR to look like this: the air component provides ISR and airborne warning and control with E-8C and E-3 aircraft, respectively; the land component provides a ground armored-reconnaissance element; the maritime component provides the recovery vehicle with HH-60 helicopters; and the special-ops component provides a SEAL team to move the survivor to a linkup point (fig. 3). The JPRCC's

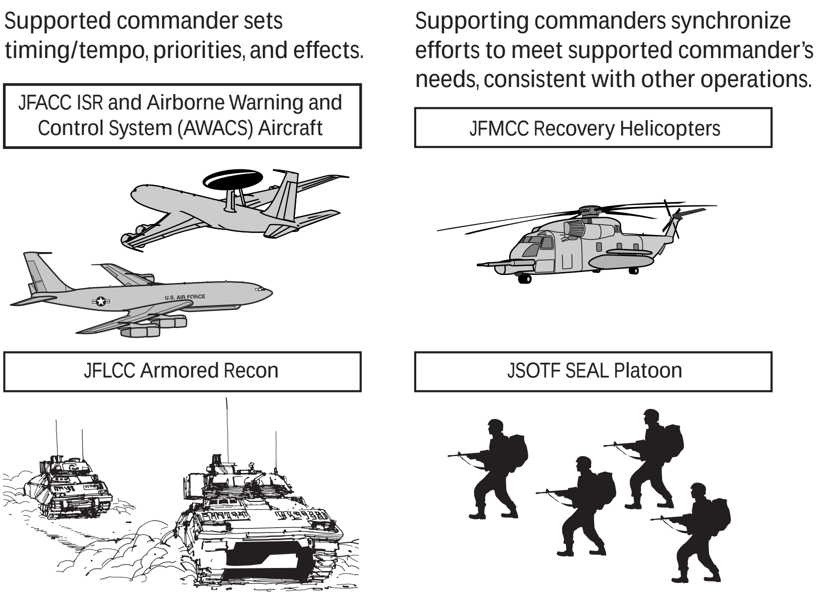

Figure 3. Personnel recovery of the future

role in such a mission simply involves designating the supported component and then monitoring operations. Although an extreme possibility, such a scenario highlights the potential interaction possible when command relationships cease to become impediments to PR operations. This will be possible only when the JPRCC relinquishes its war-fighter role and becomes a facilitator. Today's fluid battlefield, intermixing linear and nonlinear warfare, requires more agile responses. Moving the JPRCC away from the war-fighting components offers just such agility.

Many good men and women have struggled for years to improve PR and bring us the successes we've seen over the last few years. This change will capture their hard work and excellent results. It will also offer greater opportunities for more innovation and improvements to make sure that Americans who go into combat know that their nation and its forces will do everything possible to bring them home alive, no matter their situation. □

Notes

1. Personnel recovery is

> the aggregation of military, civil, and political efforts to obtain the release or recovery of personnel from uncertain or hostile environments and denied areas whether they are captured, missing, or isolated. That includes US, allied, coalition, friendly military, or paramilitary, and others designated by the [president and secretary of defense]. Personnel recovery . . . is the umbrella term for operations that are focused on the task of recovering captured, missing, or isolated personnel from harm's way. PR includes but is not limited to theater search and rescue; combat search and rescue; search and rescue; survival, evasion, resistance, and escape; evasion and escape; and the coordination of negotiated as well as forcible recovery options. PR can occur through military action, action by nongovernmental organizations, other US Government-approved action, and/or diplomatic initiatives, or through any of these.

Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms*, April 12, 2001, 405.

2. Department of Defense Directive (DODD) 2310.2, *Personnel Recovery*, December 2000, 3, par. 4.1.

3. *Joint personnel recovery center (JPRC)* is the new term proposed for the next version of JP 3-50.2, *Doctrine for Joint Combat Search and Rescue* (now in final coordination). To avoid confusion with the existing *joint personnel reception center*, I've altered the term to *joint personnel recovery coordination center*—a more accurate name and one that should become the standard. This designation also indicates its new role, distinct from the one most people associate with the current JSRC model.

4. JP 3-0, *Doctrine for Joint Operations*, September 10, 2001, describes operational warfare as the level that links tactics to strategic objectives and that focuses on the operational art (II-2).

5. JP 3-50.2, III-1.

6. European Command has created a joint personnel recovery coordination cell at its standing joint force headquarters, and Southern Command has moved the JSRC function from its air component to its headquarters.

7. JFCs always have the option of altering their force and staff structure, however. See JP 5-00.2, *Joint Task Force Planning Guidance and Procedures*, January 13, 1999.

8. JP 3-50.2, chap. 6, lists the doctrinal JSRC requirement (15 personnel in three shifts); in practice, each JSRC is task-organized in line with "mission, enemy, terrain and weather, troops and support available—time available" (METT-T) considerations. Therefore, it's not realistic to precisely predict the number of personnel required for this new JPRCC; however, the additional manning most likely will not be significant.

9. Substantial differences exist between the meanings of PR and CSAR, the former covering the holistic mission in the theater or throughout the joint operations area and the latter indicating the combat tactical task performed by designated rescue forces. Since CSAR is a subset of PR, I use *PR* as the broader, more appropriate umbrella term.

10. PR exercises are either stand-alone service events or additions to existing Joint Chiefs of Staff or theater exercises. In the latter case, they are usually minor events that would benefit greatly from locating the JPRCC on the JFC's staff.

11. JP 3-50.2, vii.

12. Ibid., chap. 1, par. 3b.

13. According to US Special Operations Command, "Civil Affairs" are the forces, and "civil affairs operations" are the mission.

14. Boards, bureaus, cells, and offices are staff elements of a JFC's headquarters that focus on a specific facet of the operation, such as the joint movement center, Joint Information Bureau, and Joint Targeting Coordination Board. JP 5-00.2 lists more.

15. These teams usually have elements from various US intelligence agencies, such as the Defense Intelligence Agency, Central Intelligence Agency, National Geospatial-Intelligence Agency (formerly the National Imagery and Mapping Agency), National Security Agency, and so forth.

16. The joint operations area is "an area of land, sea, and airspace defined by a geographic combatant commander or subordinate unified commander, in which a joint force commander (normally a joint task force commander) conducts military operations to accomplish a specific mission." JP 1-02, 284.

17. A JPRCC will gain its perspective from both augmentees (as JSRCs do now) and liaison officers, which all components send to the JFC. JSRCs have always requested augmentation and liaison officers from other components, but the latter—viewing the mission as CSAR and not PR—frequently have sent only their air planners.

18. TACON is "command authority . . . limited to the detailed direction and control of movements and maneuvers . . . necessary to accomplish missions." JP 1-02, 519.

19. JP 3-0 lists *support* as a "command authority" whereby "one organization should **aid, protect, complement, or sustain** another force . . . in accordance with a directive requiring such action" (emphasis in original) (II-9, GL-17). It can be used at any command echelon below combatant commander (the secretary of defense frequently uses this between combatant commands as well).

20. Problems with the TACON relationship caused hours of delays for both rescues during Operation Allied Force (Kosovo) in 1999. In the case of the downed F-16 pilot, the delay nearly caused the rescue force to attempt the mission under less-than-optimal daylight conditions in a medium-threat environment.

21. The 18th Airborne Corps, the original joint task force (JTF) for Millennium Challenge 02, planned to experiment with retaining the JSRC at the JTF. However, when contingency operations prevented its participation late in the preparation for MC02, the 18th cancelled the plan.

22. This change also eliminates the likelihood of a PR mission's running counter to another component's operation. During the rescue of Bat-21B (Lt Col Iceal "Gene" Hambleton) in the late stages of the Vietnam War, ground forces felt that their mission was sacrificed because the air component focused solely on the rescue of a downed airman. Although the PR mission probably didn't cause any true disruption of the ground mission, the perception was that each component fought independent and contradictory battles.

Tactical Control
Accomplishing the Mission

Tactical control (TACON) is inherent in operational control (OPCON), but moves from the authority to organize and employ forces to the use of assigned or attached forces or military capabilities to meet specific missions or tasks. Air Force doctrine now emphasizes effects-based operations (EBO), rather than just executing a tasked mission to destroy a target or planning for annihilation or attrition warfare. Now airmen must think through the full range of specific missions, consider their associated outcomes, and then choose the mission outcome that best achieves the assigned objective, while finding ways to mitigate any impediments to achieving that objective. Therefore, TACON involves more than "just" accomplishing the mission.

Joint Pub 1-02, *Department of Defense Dictionary of Military and Associated Terms*, defines *tactical control* as the "command authority over assigned or attached forces or commands, or military capability or forces made available for tasking, that is limited to the detailed direction and control of movements or maneuvers within the operational area necessary to accomplish missions or tasks assigned. . . . Tactical control provides sufficient authority for controlling and directing the application of force or tactical use of combat support assets within the assigned mission or task" (p. 519).

TACON is typically exercised by the service component commander or the functional component commander (e.g., an Air Force service component commander is referred to as commander, Air Force forces [COMAFFOR], and an Air Force functional component commander would be the joint force air and space component commander [JFACC]). Normally, TACON is delegated from the combatant commander (CDR) to the joint force commander (JFC), who then should delegate it to a component commander. However, TACON can be delegated to and exercised by any commander at any level. When OPCON is transferred between CDRs or is delegated to a subordinate commander, TACON is also transferred or delegated.

TACON allows the commander to move forces as required and to give them local direction. However, it does not include authority to change the organization of forces or to conduct readiness training. It also excludes administrative and logistical support (unless specifically included). For example, if an Air Force JFACC is given TACON of Navy aircraft, then the JFACC can task those aircraft, using the air tasking order, but does not have the authority to alter the structure or command relationships of those forces or to discipline their personnel. The service component commander retains those responsibilities. In this example, that would be the commander, Navy forces (COMNAVFOR).

In a memorandum dated September 28, 1998, the secretary of defense directed one exception to these TACON doctrinal guidelines as they apply to the force-protection mission. He directed that "geographic [CDRs] CINCs will exercise directive authority [TACON], for the purposes of force protection, in the covered countries, over all DOD personnel." This exception raises an interesting implication. When a JFACC is also the area air defense commander (AADC) and has been delegated TACON over Army Patriot batteries and naval aircraft for area air defense, the JFACC can, while acting as AADC and for the purpose of force protection, direct the movement of those Army and Navy units.

As airmen, successful mission accomplishment is our job, and receiving TACON for a mission is both a duty and an honor. Every airman must be aware of the responsibility that comes with TACON and the full range of options enabled by those additional forces, and then make the choices that lead to successful mission accomplishment.

To Learn More . . .

Air Force Doctrine Center. "Tactical Control (TACON)." *Doctrine Watch*, no. 4, December 2, 1999. https://www.doctrine.af.mil/DoctrineWatch/DoctrineWatch.asp?Article=4.

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine*, November 17, 2003. https://www.doctrine.af.mil/Library/Doctrine/afdd1.pdf.

The Nonrescue of Corvette 03©

Col Darrel D. Whitcomb, USAFR, Retired

Editorial Abstract: "These things we do so that others may live" is the motto of Air Force rescue forces. However, sometimes a combination of factors such as a shoot-down location in a high-threat environment, not having aircraft available to search for survivors, having inadequate radios, or using difficult command and control structures can impede a successful rescue. Although the lessons learned from Corvette 03 seem to repeat the nonrescue of a fighter crew in North Vietnam 18 years earlier, these lessons have initiated immediate and long-lasting improvements in search-and-rescue operations.

THE NEWS WAS bad. An American fighter had been shot down deep in enemy territory. Both crew members were on the ground and slightly hurt. Rescue efforts were ongoing, and rescuers had established contact with the pilot and the weapon systems officer (WSO) using their call sign, Jackal 33. Nevertheless, because of political constraints, recovery efforts were delayed. It was late December 1972, and Air Force and Navy aircraft were pummeling North Vietnam as part of Linebacker II.

The crew of the downed F-111A, Capt Robert Sponeybarger, pilot, and Lt William Wilson, WSO, were located about 50 miles west of Hanoi. Although landing together in their aircraft's survival capsule, they were now separated by several hundred yards of dense jungle. Rescue forces located in Thailand worked tirelessly to rescue them, and fighter aircraft passing through the area were able to determine the general location of both. The rescue task force had to wait for two days because of a bombing halt that the president had directed. Unfortunately, enemy forces were nearby and used the respite to capture Sponeybarger. When the bombing halt ended, Jolly 73, an HH-53 Jolly Green from the 40th Air Rescue and Recovery Squadron based at Nakhon Phanom, Thailand, was able to get into the area and locate Wilson. However, as they came to a hover and, using the recovery cable, began lowering the aircrew extraction device, enemy gunners opened up on the vulnerable helicopter. As the bullets whizzed by, Wilson made a dash for the Jolly Green's jungle penetrator. Within inches of reaching that objective, the WSO lost his footing and fell down an embankment. Then a heavy-caliber machine gun put several bullets through the Jolly Green's windscreen just above the pilots' helmets. Capt R. D. Shapiro, the HH-53's aircraft commander, quickly reassessed the situation and decided to depart instead of repositioning for another attempt—the enemy's reaction was just too intense.

As they headed west, the helicopter crew soon discovered that the hostile fire had damaged their aircraft and rendered it unable to in-flight refuel. Although they did not have enough fuel to reach Thailand, they were able to land on a mountain in northern Laos and a backup helicopter soon picked them up. A third helicopter landed near the stranded HH-53 to recover its classified equipment, but hostile fire forced them to depart. A-1E Sandys were then given the order to destroy Jolly 73 to prevent it and its equipment from falling into enemy hands.

The North Vietnamese captured Wilson the next day as he tried to evade. The combination of political constraints and the intense enemy reaction had foiled a successful rescue attempt.[1]

Does history repeat itself? It is a pungent question.

A little more than 19 years later, American and allied air forces were engaged in another strategic air campaign. This time, the enemy was Iraq, and "Desert Storm" was the conflict's designation. Initial strikes began on January 17, 1991, directed at strategic targets and the Iraqi air defenses. By the third day, Iraqis started firing surface-to-surface "Scud" missiles at Israel. Although they were relatively inaccurate and had little tactical value, strategically they could affect the allied coalition against Iraq if they were successful in goading the Israelis into a response. Lt Gen Charles A. "Chuck" Horner, dually assigned as the commander of US Central Command Air Forces (CENTAF) and the joint force air and space component commander (JFACC), was ordered to attack the missiles. He, in turn, directed Brig Gen Buster C. Glosson, his director of operations, to plan and execute the attacks. Glosson saluted smartly and immediately went to work in the tactical air control center (TACC).

A package of 24 new F-15Es from the 4th Tactical Fighter Wing (TFW) based at Al Kharj Air Base, Saudi Arabia, was diverted from other preplanned missions to hit the suspected Scud missile sites and supporting targets in western Iraq. Coming less than six hours before takeoff, the changes caused near chaos among the crews as they scrambled to collect intelligence and request support assets to attack the sites. The area was extremely dangerous because of all the enemy defenses in the immediate vicinity.

Flying as the number-three aircraft in Corvette flight was Col David W. "Dave" Eberly, the wing director of operations, and Maj Thomas E. "Tom" Griffith. Eberly was a last-minute change, having volunteered to fill a hole in the schedule.

As the aircrews walked to their jets, they received the actual aim points, or desired mean points of impact (DMPI), that they were to use during their attacks. As they programmed their onboard flight computers, the assigned time-over-targets (TOT) were changed twice. Lt Col "Scottie" Scott, Corvette flight leader, said to Colonel Eberly, "This thing is a goat rope. It's the kind of mission that gets people killed."

Silently, Eberly concurred. He knew there were SA-2s and SA-3s in the target area, and the ALQ-135 jamming pod on his aircraft did not have a capability against those surface-to-air missile (SAM) systems. He would have to rely on the supporting F-4Gs and EF-111s to suppress the SAM sites.[2]

The situation continued to worsen after their takeoff. Corvette flight had trouble finding their assigned refueling tankers in the thick clouds. Then they learned that their supporting F-4G Wild Weasels had not received the new TOTs and would not be on station when they entered the target area.

As the strike aircraft flew west, their misfortune continued. Scott had requested and been given EF-111 jamming support. A flight of two had arrived on station and set up their orbits to electronically jam the Iraqi missile sites. Soon afterwards, however, an Iraqi MiG-25 took off from its home base, intent on downing them. It avoided engagement by allied air-to-air units and fired three missiles at the two EF-111s as it darted through their orbits. Both EF-111 pilots took evasive action and defeated the missiles. However, those defensive reactions forced the two aircraft out of their jamming orbits. Not knowing where the MiG had gone and not having an autonomous self-defense capability, the two pilots turned south and headed for the safety of Saudi airspace. The F-15Es entered the dangerous skies of western Iraq without their planned F-4G and EF-111 support.[3]

Scott led Corvette flight toward their assigned sites, unaware that his flight had also lost its electronic-jamming support. Thirty miles from the targets, they began seeing the airbursts of radar-controlled antiaircraft artillery (AAA). At 10 miles, they came under attack from SA-2 and SA-3 radar-directed missiles. Corvette 01 and 02 made their attacks. Just as Corvette 03 was about to release his bombs, Eberly's radar-warning receiver indicated that an SA-2 was tracking his aircraft. Almost immediately, he spotted a missile approaching from the right; he aggressively broke into its path, defeated it, and watched it streak by. He then rolled back to the left to continue his attack when the bright-white explosion of an undetected second missile violently rocked his aircraft.

Eberly scanned the instrument panel and was overwhelmed by the rapid illumination of an ever increasing number of warning lights. The missile had ripped apart his aircraft, and it was dying fast. In the backseat, Tom Griffith tried to make a "Mayday" call on the radio. Instinctively, Eberly grabbed the ejection handle and pulled it—the designed ejection sequence functioned properly and immediately ejected Griffith. After the short but proper delay, Eberly was ejected from what was left of the aircraft.[4]

Both men floated down through the bitterly cold night air. Griffith landed uneventfully. Eberly, however, had been knocked out by the ejection and was confused as he came to on the ground. He had not taken any refresher courses in combat survival during Desert Shield. Nor, because of the circumstances, had he taken time to develop a premission evasion plan with the intelligence section back at Al Kharj. As his head began to clear, he grabbed his parachute and moved away from his ejection seat, leaving the rest of his survival kit behind.

Since the two men could not see each other, Eberly took out his PRC-90 survival radio and made an emergency call, "This is Chevy—." He stopped, and then remembered that Chevy had been his call sign on a previous mission. He started again, "This is Corvette 03 on guard. How do you read?" There was no answer. Sensing Griffith, who also had a PRC-90, was not too far away, he continued his efforts and soon made contact with his crewmate. Visibility was good; using various distinctive landmarks, they were able to rendezvous within 15 minutes.

Griffith had all of his survival gear. Together, they moved off to the southwest. As the sun came up, Griffith could see that Eberly had a gash in the back of his head and a bad scrape on his face. He tended to him as best he could. Then they wrapped themselves in the parachute and got some sleep.

Corvette 01 had quickly contacted an orbiting early warning aircraft and reported that Corvette 03 was down. They, in turn, immediately notified the joint rescue coordination center (JRCC). The center was physically colocated in the TACC for good reason. General Horner, as directed by USCINCCENT OPLAN 1002-90, was also responsible for theater rescue, and the JRCC, under the direction of Lt Col Joe Hampton, carried out that responsibility. Although each service component retained primary responsibility for carrying out its own recoveries, they would contact the JRCC whenever they needed help. During the buildup for the war, the Air Force did not deploy any rescue helicopters to the theater; so, when CENTAF needed helicopter support, it would have to ask one of the components. Approval, however, was not automatic because each component retained operational control (OPCON) of its own assigned assets. The Air Force Special Operations Command (AFSOC) had deployed squadrons of MH-53s and MH-60s into Saudi Arabia. These were the optimum helicopters to fly deep recovery missions into Iraq, but they were under the OPCON of Special Operation Command Central (SOCCENT).

SOCCENT also had Navy and Army helicopters assigned to it, and as those forces arrived in theater, it spread them out over many airfields in Saudi Arabia. The commander of SOCCENT was Col Jesse Johnson, US Army. His top airman was Col George Gray, commander of the 1st Special Operations Wing (SOW), based at Hurlburt Field, Florida, and the parent wing of the MH-53s and MH-60s. Also with him was Col Bennie Orrell, his director of operations. This was fortuitous because Orrell had been a career rescue pilot, had received the Air Force Cross for a daring 1972 rescue in Laos, and knew combat rescue better than any man alive.

Combat search and rescue (CSAR) was SOCCENT's first and primary mission during the entire conflict. Upon arrival, its various assets immediately prepared to execute rescue missions. However, Colonel Gray repeatedly emphasized that his crews could not perform the entire CSAR mission. CSAR was a process that involved locating, authenticating, and recovering downed airmen. His helicopters could not do the search-and-locate portion—especially in high-threat areas. Combat in Southeast Asia (SEA) had shown that helicopters were too vulnerable to enemy missiles and guns—Iraq had untold thousands of them.

During recoveries, AFSOC helicopters, equipped with highly accurate global positioning systems (GPS), could quickly and precisely navigate to the known location of downed aircrews, make the pickup, and quickly dart out of high-threat areas—but they could not be expected to loiter there. Johnson and Gray established three criteria for launching their helicopters on recovery missions: (1) location of the survivor(s); (2) evidence of aircrew survival, either a visual parachute sighting or an aircrew's authenticated voice transmission;[5] and (3) favorable enemy-threat analysis.[6]

Following the Vietnam War, the Air Force developed satellites and intelligence-collection capabilities, such as the RC-135V/W Rivet Joint aircraft, which, theoretically, have the ability to locate downed crewmen in enemy territory with a reasonable level of accuracy. However, this capability had not yet been tested in combat.[7] On the second day of the campaign, SOCCENT had made an unsuccessful attempt to pick up a downed F-16 pilot. Although the Iraqis had immediately captured the pilot and made the recovery impossible, the MH-53 crews had proved that with good intelligence and accurate navigational data, they could fly into enemy territory and operate in relative safety.

The news of Corvette 03's shoot down arrived in the JRCC at a busy time; it was a hectic night with numerous reports of aircraft down and emergency beacons being detected. The JRCC controllers had to sort through the data and determine whether there were, in fact, survivors and then locate them. One of the members of Corvette flight reported that the aircraft had gone down at the approximate coordinates of 34˚13' north, 040˚55' east, about 10 miles southwest of the target area near Al Qaim. That was a start, but considering that location was reported by an aircraft which was itself under fire and moving at over 500 miles per hour—covering a mile every seven seconds—the confidence in the accuracy of the location was not good enough to launch the vulnerable helicopters into such a high-threat area. Search-and-rescue satellites (SARSAT) also reported location data, but that system's circular error probable (CEP) (the area in which 50 percent of the survivors should be found) was also too large to commit helicopters to a rescue attempt.

Colonel Hampton, the JRCC director, remembered how the data flowed in: "We knew they punched out. We had intel [intelligence] on them from the RC-135 that the Iraqis were looking for them for a while and one ground group said that they had captured them."[8]

Hampton wanted to launch helicopters immediately, but he did not have the authority to do so.[9] In accordance with the theater CSAR plan, the JRCC passed the data to SOCCENT where Colonel Gray began to intensively study the situation. He could stage MH-53s along with supporting MH-130 tanker aircraft out of Arar Air Base in northwestern Saudi Arabia.

Gray also had the assets of Proven Force to consider. Those were US forces that had been deployed from Europe to Turkey to open a second front in the north. Its aircraft included a task force of MH-53s and MH-130 tankers. Helicopters from either location would need the tanker support because of the long ranges involved. That would put more men at risk because that section of Iraq was one of the most highly defended areas in the entire country and extremely dangerous.[10] Looking at the map, Gray divided Iraq into two sections. Above latitude 33˚30' north, he would task Proven Force forces; below that latitude, he would use forces located in Saudi.

JRCC did not report an accurate position for the aircrew, or even if they were alive and free, when they passed the mission to the SOCCENT. Although Gray would not send his helicopters in to do a search, it did appear though, that the general area in which they could expect to find the men, if they were alive and still free, was above the dividing line. Gray, therefore, suggested to Colonel Johnson, his boss, that they pass the mission and what was known to the Proven Force

Desert Storm theater of operations

crews.[11] Johnson concurred, and the JRCC sent an alert message to the crews in Turkey, who, in turn, began their initial planning.[12]

Throughout the night and next morning, the JRCC worked with various intelligence assets to determine the status and refine the position of the survivors. They alerted the various collection elements to be vigilant for any radio calls from the two men. Such transmissions would be dangerous for the survivors; the Iraqis had excellent homing capabilities and could track any calls they might make using their PRC-90 radios. Additionally, intelligence sources suspected the Iraqis of setting off SAR beacons as tactical deception decoys.[13] The JRCC had to resolve the unknowns and refine the data to avoid potential traps.

Additionally, Gen Buster Glosson indicated that there were some things going on behind the scenes, which indicated that "other" governmental agencies were also working to rescue the two men. That possibility was discussed at SOCCENT, and the JRCC personnel were aware that some other possible options were being considered.[14]

Johnson concurred with Gray's suggestion to request access through Syrian airspace to enable a possible helicopter mission from Turkey and forward the request up the line to United States Central Command (USCENTCOM). They, in turn, made a formal request through diplomatic channels for authorization to use Syrian airspace. USCENTCOM expected Syrian approval since it was an ally in the war.[15]

As Eberly and Griffith slept, intelligence sources picked up new signals that seemed to indicate another downed aircraft in the area. They monitored what sounded like a Mayday call from someone using the call sign of "Crest 45A." The JRCC quickly checked with the TACC and the Proven Force command center and determined that this call sign had not been used.[16] A couple of hours later, intelligence reported that Bedouins in the area had apparently found the wreckage, but not the crew, of Corvette 03 and had reported it to a nearby Iraqi air defense unit.[17] Also during that time period, a civilian entered the American Embassy in Amman, Jordan, claiming that he had information that Eberly was alive and suggested that he could turn him over to the American government for a reward. It took time to investigate this bogus claim.[18]

As time passed, there seemed to be little happening, and some of the TACC personnel began to question what appeared to be a lack of activity by the rescue forces. Capt Randy O'Boyle, an MH-53 pilot assigned in the TACC, began to take heat from some of the fighter guys. He remembered that when some of the F-15 guys were giving him grief, he said, "Look, next time you're out there flying around, why don't you just descend down to altitude, drop your gear, drop your flaps, and just go look for somebody on the ground in one of those spots where you think there is somebody. And, as soon as you get him, then you let us know. You just can't go trundling into some place in a high threat environment without knowing exactly where the guy is."[19] His view was shared by Col Ben Orrell:

> I'm not kidding. You could see those Paves [MH-53s] 50 miles off. There was no hiding them. That's a big ole' slow moving target—I was reluctant to go cruising in there in the daytime. There certainly may have been a situation where we would have done it, but if you don't have a guy talking to you on the radio, it's pretty hard to convince me to send another two or three crews in there. . . . The only way we were going to survive as a rescue force in that environment was to fly at night. And, I don't think that the fast movers [fighter pilots] ever accepted the fact that we were not just going to come plunging in there in daytime like we had done in Vietnam. Had we done that, we'd have lost more [crews].[20]

However, that was exactly what the F-15E crews expected. When Eberly did not return, Lt Col Bob Ruth, his assistant, became the wing's acting director of operations. As Ruth remembered, "When we were over in SEA, if an airplane went down, we did dedicate just about any air we could to try to suppress the area to try to get the survivors out."[21] But that was not happening here. The F-15Es were held for the anti-Scud missions. Colonel Ruth reflected on that when he said, "Everybody just kept doing his mission, and everything was handed over to the [C]SAR folks."[22]

During the day, several strike flights flew through the Al Qaim area. As each would pass, Eberly or Griffith would attempt to make contact. One of those groups was a flight of four F-16s from the 10th Tactical Fighter Squadron (TFS), led by its commander, Lt Col Ed Houle. As with Corvette on the previous night, his mission had also been a last-minute change. Originally, he had been part of a 40-ship package of F-16s, F-15s, and other assorted support aircraft that had planned an attack against a target in Baghdad. Well into the planning process, they had been broken up into smaller packages and directed to hit Scud sites in west Iraq.

During Houle's preparation and briefings for the new mission, no one told him that a crew had been shot down in the Al Qaim area the day before. Approaching his target he heard, "This is Corvette 03, does anybody read?" Not expecting such a call, he let it pass and remained focused on striking his well-defended target that had very active AAA and SAM sites. Upon leaving the area, he checked with the airborne warning and control system (AWACS) aircraft and asked, "Hey, who is Corvette 03?" The controller responded, "Why, did you hear something?" Ed replied that he had and told him what he had heard; the controller thanked him and directed him to return to his base.

Landing back at his base and now fully suspicious, he walked into intelligence for the mission debrief and asked, "Who the hell is Corvette 03?" The intelligence officer informed Houle that Corvette 03 was an F-15E that had been shot down in the Al Qaim area during the previous night and that rescue forces were trying to locate the crew. Houle's cockpit mission tape was pulled and forwarded to the 4th TFW, where unit members identified the voice as that of Colonel Eberly.

This all came as a complete surprise to Houle; neither he nor anybody in the flight had been briefed that there was a downed aircrew in that area. If they had, they would have been on the lookout for them. Houle made sure that the premission briefing procedures were changed to ensure that all of his pilots were briefed on downed crews and CSAR efforts going on in any areas in which they would be flying. Houle went a step further and passed this procedure to the JRCC, who then began to send out information on all downed aircrews to all units, and then updated the report every 12 hours. Houle also suggested to higher authorities that downed aircrews use the term *Mayday* instead of just talking on the radio. That way, they would get the immediate attention of any listening aircrews.[23]

That evening, Chevy 06, another flight of F-15Es, was passing through the area, and one of its crews made momentary voice contact with one of the downed airmen. Chevy 06's position at that time was almost 30 miles southwest of the target area and did not correlate with any other reports. Lt Col Steve Turner was the flight lead of Chevy 06 and Griffith's squadron commander; he was certain that he had just talked to Griffith.[24]

After returning from his mission, Turner called the JRCC and spoke with some of the controllers. When asked, he confirmed that he had not asked either man any private questions to authenticate their identities. Nevertheless, since he had served with Griffith for three years, he was adamant and absolutely certain that it was Griffith on the radio. Turner then became very insistent that more be done to get them out. He was coming to the opinion that the rescue forces were slow-rolling them for some reason. When told of the difficulties that they were having locating the guys, he suggested, strongly, that an F-15E be sent in, not as part of a strike package but specifically to find the guys.[25] He was told that the F-15Es were needed to hit targets and that CENTAF would send in F-15Cs to search.[26]

The 4th TFW commander was also upset, called the JRCC, and, as quoted by one of his young majors, asked, "Is this incompetence or is it just sheer cowardice?"[27] Tension was building in the TACC to do something to rescue the aircrew. Some wanted to send the helicopters regardless; others were more cautious. Lt Col Joe Hampton took direct action to help find the accurate location of the survivors, saying, "Every mission that went up into that area we tasked to make radio calls, to monitor the frequencies. We tried everything that we could in order to make contact with those guys."[28]

Consternation from the apparent lack of action spread through the 4th TFW. Maj Richard Crandall, another F-15E pilot, said, "You can't believe how angry we were that they were not going up there looking for those guys. We were so angry that Al Gale and I actually proposed to take a vehicle and drive up there to get them."[29]

Colonel Gray was the one who was holding the line. He knew that without good authentication that the voices on the radio were, in fact, Eberly and Griffith, it could be an Iraqi trap. The North Vietnamese had done this numerous times in SEA, and he did not want to lose a helicopter crew or fighter escort to the enemy in this war. Solid procedures were in place to authenticate downed crewmen, but they were not being followed, and he had no control over that. That was the JRCC's business. Although the pressure was building to do something, he did not want to commit a helicopter crew until he was sure.[30]

Although Colonel Hampton, the JRCC director, was not hopeful about the chances of recovery or even their ability to make a successful effort, he said,

> The guys could have still been down there, and if you can do it without losing anybody to do it, great. But as far as pushing for a mission at that point, we weren't in that position, and we left it up to the SOC [SOCCENT] guys to determine. If you want to go in there and do it, fine, okay—but we didn't agree on coordinates. We had a position that was farther to the east. Why they went to where they did I think was based on some cuts from an RC-135. I'm not sure that was a real good position on the guys. That was probably two-day-old data at that time, and if your RC-135 is down here [in Saudi] and you're doing DF up to that position . . . I know their gear is sophisticated; however there's got to be some precision there.[31]

Up at Batman Air Base in Turkey, the Proven Force MH-53 crews were busy planning contingencies. They were collecting all available information, although this was a very difficult task at such a remote location. Given the general area of the survivors, it was obvious to them that flying east in Turkey to get into Iraq and then southwest to the Al Qaim area was much too long and dangerous. Capt Steve Otto, an MH-53 pilot, remembered the obvious and said that if we stayed in Turkish and Iraqi airspace, "We simply would not have the range to make it down towards Al Qaim. So, given the threat and that large obstacle in the tri-border area, we knew that if we were going to get to Al Qaim, we were going to have to fly over Syria. We started asking for overflight permission to go through Syria."[32]

But that was not all that concerned the Pave Low pilots. Again, as Otto remembered,

> We had a call-sign, but we did not have any survivor data or any ISOPREP information. Perhaps more disturbing was that we had three last known positions and they were in a triangle which was about 20 miles on each leg. The bad part about it is that had it been in a low-threat area, it would have been no big deal, and we probably would have been less intimidated. But the Al Qaim area had very intense AAA and SAM defenses. We knew that that was one of the early target areas, and Corvette 03 had been shot down striking targets in that vicinity. . . . This was really an intensely defended area.[33]

Back at Al Kharj, after listening to the tape that Ed Houle had forwarded to the 4th TFW, Col Bob Ruth was convinced of Eberly's voice and had it flown to the JRCC. There, Hampton and his controllers listened to it, and with the conviction of the 4th TFW guys that it really was their guys, they gave their assurances to Colonel Gray at SOCCENT. Gray became convinced of positive voice contact, acquiesced, and directed that a mission be launched. He formally tasked the combat rescue forces in Turkey, and the timing of his decision was such that those forces could still execute that night in the dark—their preferred method of operations. However, other issues existed that had the potential to delay the mission. Capt Grant Harden and Captain Otto, the two Pave Low pilots, felt that they did not have enough solid data to properly plan and execute the mission. They immediately elevated the matter to their squadron commander; he went to work to get them better data, especially a more precise location for the survivors.[34] The other issue was that Turkey, still skittish about the entire Proven Force operation, had refused them launch authority. By the time these issues were resolved, they had lost the night.[35]

Getting into the Al Qaim area in a helicopter was a tough tactical challenge due to the high level of enemy defenses. Colonel Gray had already concluded that any approach from the south with his helicopters and their tankers would be almost suicidal. From the north, the problem was similar; any approach that came down out of the mountains along the Turkish-Iraqi border and then flew across the flat midland of Iraq would be just as dangerous. However, an approach through Syria looked much safer and was the route Gray had recommended at the beginning. Syria had not yet granted a flight clearance for the mission and, instead, had recommended that they send in a Syrian team to pick up the two American flyers. To add further confusion, a Bedouin tribesman had come to the American Embassy in Jordan claiming to have a "blood chit" from one of the flyers and wanted to trade the two men for a new truck.[36] All of this political wrangling resulted in further delays.

Eberly's spirits soared the next day when he heard what was obviously the execution of a CSAR effort. He called on the radio, but was abruptly told to clear the frequency because a rescue operation *was* going on—it just was not for him and his WSO. It was, in fact, for a Navy F-14 crew who had gone down well to the east.

At the JRCC, Hampton continued to task every aircraft going into that area to listen for and try to locate the two men.[37] That evening an F-15C pilot, Mobil 41, made contact with the men. He heard their emergency beacon and directed them to go to the backup frequency.

Switching over, one of the downed aircrew said, "Go ahead."

Mobil 41 responded, "We are just trying to get hold of you to see if you're still around. What is your physical condition?"

Eberly responded, "Physical condition is good. Alpha and Bravo are together. We are approximately 10 miles northwest of [garbled]."

Mobile 41 responded, "Corvette 03, we read you. Will be flying closer to get better radio contact."

Anxious, Eberly asked, "Do [you] understand our position?"

At that point, somebody came on the frequency and shouted, "SAR in effect, get off of this frequency."

It was a repeat of what had happened earlier in the day. The interloper did not identify himself. But Mobil 41 was not able to reestablish contact with the crew of Corvette 03, verify their position, or authenticate their transmissions.

Eberly reluctantly concluded that they were not going to be rescued. He talked it over with Griffith, and they decided that since they were so close to Syria, they would attempt to walk out. They had an out-of-date map and felt that they had a fairly good idea of where they were. They set out walking north and although they encountered some Bedouin camps and even some vehicles, they remained undetected.

As they approached what they thought might be the Iraqi-Syrian border, Eberly took out his radio and unsuccessfully attempted to make some more calls. He then spotted what appeared to be an abandoned building; both men were cold soaked and the idea of being inside, sheltered from the wind, was very appealing. Eberly was also very dehydrated and needed some clean water. As he looked through one of the windows to see if it was safe, a dozen soldiers ran out of the building, and on that cold, early morning they were captured.[38]

Eberly and Griffith's capture was unknown to the rescue forces, who did realize, however, that no one had been able to contact the two downed airmen. Throughout the day, the strike flights that hit targets in the Al Qaim area had continued to call for Corvette 03 with no result. Intelligence assets kept an ear tuned for any sign of the men but detected nothing. Colonel Johnson, the SOCCENT commander, discussed the mission and reviewed all the known data with the Special Operations Command, United States European Command (SOCEUR) commander. Finally satisfied that the mission had a reasonable chance of success, Johnson directed that the rescue mission be executed, contingent on the Syrians' approval to use their airspace.

The Proven Force crews were primed and ready to go in that night. Captain Harden and Captain Otto would again fly the two MH-53s, but this time with better intelligence and the necessary data on the survivors. They planned to make the flight through Syria, escorted by MC-130 tanker aircraft. Their arrival in the Al Qaim area would be coordinated with several air strikes designed to divert the attention of the SAM and AAA sites. SOCCENT and the planners at Batman felt that the supporting air strikes and use of Syrian airspace would give the rescue helicopters and crews the best chance of success and survival.

At launch time, Otto, Harden, their crews, and their massive MH-53s were ready. On board each helicopter were two pilots, two flight engineers, two door gunners, two pararescuemen (PJ), a combat controller, and an Army special forces team for ground security. Although the Syrians had still not approved the use of their airspace, Otto and Harden received direction to launch when they reported ready.

They started engines and took off; as they approached Syrian airspace the command center told them to press on to the objective area, without receiving the necessary clearance. Twenty minutes later Otto and Harden were notified that Syrian approval had been received; that message was confirmed by numerous additional satellite communication (SATCOM) radio calls, which soon became a distraction.

They flew south toward Al Qaim for two hours at about 100 feet above the ground and on a flight path that paralleled the Iraqi-Syrian border. There was no moon, but starlight illumination was enough for their night-vision equipment to be effective. Capt Matt Shozda was serving as Harden's copilot and found the flying that night to be very challenging. They had not yet gotten used to flying blacked out over shifting sand dunes and having their attention refocused every time the radar altimeter indicated less than 10 feet above the ground.[39] Approaching the Euphrates River, a Syrian SA-6 site, off their right side, locked-on and tracked them before they turned to defeat it.[40]

Captain Harden remembered, "Our plan was to hit a final IP [initial point] and then make a run in. The run in to the exact location would be based on contact. If there were no contact, we would not go beyond the final area."[41]

The mission was being watched as it proceeded by nervous commanders back in the United States. Brig Gen Dale Stovall, then the vice commander at AFSOC, remembers that "we held our breath. There was a tremendous amount of pressure to send [the helicopters] in to search when we didn't have a good fixed position on those guys."[42] He was well aware of the risks as it brought back powerful memories of Jolly Green crews sent in to North Vietnam to look for downed fighter crews in 1972. The high losses on those missions had been suffered by Stovall's squadron mates—men whose faces he could still see.

The two blacked-out helicopters now turned southeast, parallel to the Euphrates River, entered Iraq, and approached the well-defended area of Al Qaim. Low and slow, they moved toward the hold point. Captain Harden had requested that air strikes against the defending Iraqi SAMs and AAA precede their arrival. He had also requested that one fighter would arrive just ahead of the helicopters, act as an on-scene commander (OSC); that pilot would contact the survivors, authenticate their identities, and have them ready for a quick pickup. In spite of those requests, Harden recalled that "the entire sequence, as always happens, did not come off as planned. There was supposed to be a diversionary covering air strike. It was late and short. When we went in, we were supposed to have a high bird make contact. That never happened."[43]

Without an OSC, they were on their own. Captain Otto describes how the mission proceeded:

> We got down to the hold point and we started holding in kind of a "figure eight," not to fly over the same ground track. We were about a mile into Syria. Our ROE [rules of engagement] from our squadron commander was that we were not going to fly or commit into the threat area around Al Qaim unless the survivors came up on the radio. We noticed that there was a slight rise and we could stay somewhat masked. As all of this is going on, the giant light show is going on with the AAA. It was towards the strike aircraft but randomly. It wasn't guided toward us. It was just fired up into the air. Which is kind of the way they seemed to do things. We eventually got there and realized that the fighters were not going to get Corvette 03 up on the radio.
>
> We orbited for about 5 minutes and expected to hear them call. We were on time as we got to the orbit point. It coincided perfectly with the strikers getting there.
>
> Then eventually, Grant and his copilot Matt Shozda realized that it was just getting screwed up, and we were going to have to do our own authentication. And Grant told us to stay down low. He climbed up a couple of hundred feet, maybe 500 feet, and just started talking on the radio . . . trying to get them up on the radio. Probably after about a minute delay, we started to notice that the Iraqi AAA started to get real intense, once we had talked on the radio. And even in the aircraft, we felt that they were intercepting and DFing us. Then the fighters joined in trying to get them up on the radios. Corvette 03 only had PRC-90s. And we knew as long as we were there and talking on the radio, the odds of the mission being compromised were greater. Bottom line is that we stayed down there for almost 30 minutes orbiting and calling on the radio. Never heard a word from Corvette 03. Then, reluctantly, without radio contact, we were done. We flew back to Turkey.[44]

Captain Shozda in the other aircraft had similar memories:

> I got on the radio and started trying the different frequencies to contact him. Somewhere at that point, we realized that the SAR net was nothing more than a radio-controlled AAA, pilot-controlled AAA. We would key the mike and they would start firing. I told Harden, "Look! They're DFin' us. Watch this!" So I made a radio call and they started shooting again. He told me, "Cut that out!" They definitely had a trap set up for us. They were waiting for us, because the final location that we got . . . [was] in the same general area . . . [and is] where all the AAA was coming from.[45]

With no contact, the two Pave Lows left the area and returned to base. Arriving at Batman, both crews went into crew rest. The next day, they were back on the alert schedule. Within a few days, their unit had established a communications link with higher headquarters that enabled them to get daily intelligence updates and a copy of the air tasking order. Whenever allied crews were flying over Iraq, MH-53 crews at Batman were on alert for combat recovery—it was their primary mission.

A few days later, the MH-53 crews at Batman got a chance to see the CNN footage taken in Baghdad on the first night of the war. They could not help concluding that the AAA seemed much less intense in Baghdad than what they had seen near Al Qaim.[46]

For the next several days, flights into the Al Qaim area continued to call and listen for Corvette 03. Those efforts were to no avail since, unfortunately, that aircrew had been captured, as mentioned previously, and was on their way to Baghdad. However, the saga of Corvette 03 was not over, and the men of the 4th TFW were now very bitter about the nonrescue of their mates. Those feelings peaked a few weeks later when they saw Eberly's face on CNN—as a POW; it hurt to see him in those, perhaps avoidable, circumstances. To a man, they had been more than ready to help in the rescue effort. Colonel Ruth remembered thinking that "if they [JRCC] had called down and said 'Hey I need a 4-ship. Can you round up enough people?' We would have had people . . . the planes . . . could easily have done along those lines without impacting the ATO [air tasking order]. But we were never asked."[47]

On a more personal level, a pilot expressed the feelings of the wing's aircrews: "Our DO [director of operations] and backseater were on the ground for three and a half days in western Iraq. Nobody would go in and pick them up; and they eventually became prisoners of war. Before the war, the special operations guys came down to talk to us. 'No sweat,' they said, 'We'll come and get you anywhere you are.' That from my perspective was a big lie. Nobody was going to come and get you."[48] The 4th TFW commander said,

> It seemed to me that the forces running the SAR wanted a perfect situation. Before they would launch they wanted to know exactly where they were, that they had been authenticated, on, and on. I mean, when we got the tape I had [Kenneth M. "Mike"] "Slammer" DeCuir, Griff's roommate and supervisor when they were running stan eval, listen to the tape and verify that it was Griff. But those guys at JRCC would not take our word for it. So we fly the tape to Riyadh and they say, finally, "Yep now that we have heard the voice, we believe what you heard is in fact true." I mean it was frustrating, beyond belief, that we had to prove to others that, yes, there were people out there who needed to be picked up. What frustrated me the most was that I couldn't push the right buttons to get the SAR going. Horner and Glosson, my bosses, would have broken their necks to get up there, but they were running the air campaign and had no control over the SAR effort.[49]

Gen Buster Glosson was also frustrated by these events and remembered some heated discussions that he and Capt Randy O'Boyle had about SOCCENT's response. O'Boyle repeated that there were places that helicopters could not safely go. As Glosson recalled,

> Randy is 100% correct on that issue unless I made the decision I was willing to lose them. If I'm willing to lose them as the commander, I should have the prerogative to send a helicopter, or send two, or three, understanding I may lose one of them. That's my decision. It should not be someone else's decision. I am not saying you send people into harm's way just to say you did it. But many times . . . you can assist the CSAR effort with distractions in a way that a helicopter can sneak in and not have near the exposure. During Desert Storm, AFSOC [SOCCENT] wanted to look at everything in isolation. They wanted to say, "Oh, helicopter[s] can't get in." Randy and I had a few conversations on this. I said, "Randy, stop letting those guys, if you can, look at this in isolation. I can make all hell break loose a quarter of a mile from where we want to pick the pilot up, I can make sure the people on the ground are only concerned about survival." Bottom line, you can't look at CSAR, or anything else during a war, in isolation.[50]

Neither Horner nor Glosson could launch the rescue helicopters because Gen H. Norman Schwarzkopf had given that responsibility and authority to the commander of SOCCENT, Colonel Johnson. Johnson's air commanders, well schooled in the realities of rescue behind enemy lines, delayed the effort until they felt that they had the best chance of rescuing the men and not losing their helicopter crews in the process. It was an unfortunate misunderstanding fueled by the "fog of war." The fighter guys expected to be picked up. For years, they had heard the stories of the old Vietnam vets who "knew" the rescue guys would come. However, when they did not, for reasons that they could not know or understand, they lost faith and condemned those responsible.

Yet, Colonel Gray was adamant in his logic. "I wasn't going to send guys into a situation where we were automatically going to lose a helicopter and 5 more guys."[51]

Lt Col Pete Harvell, a CENTCOM staff officer in the J-3 recovery section, watched all of this and was somewhat dismayed by the attitude of Air Force officers who, in their enthusiasm, were so quick to send special operations forces (SOF) helicopters into such a high-threat area. He said that "this is an issue of recurring special operations' concern in that non-SOF people have a tendency to commit SOF forces in unrealistic ways. This is a recurring theme that the SOF guys have got to fight. They say, 'Send the SOF guys.' It's not a SOF mission. It's easy for them to say, 'Mount up the SOF guys and have them do this.' They don't understand what our strengths and weaknesses are and what we can and cannot do."[52]

Concerned about the failure and its impact, the commanders in CENTAF tried to address the problem. Analysis indicated that the PRC-90 radio used by the crews was clearly inadequate for the conflict. It had the ability to use only two frequencies, which the Iraqis easily exploited and compromised. The PRC-112 was a newer and better radio, available in limited numbers. It had more frequencies and a covert transponder identification and navigation aid that provided SAR aircraft with range and bearing information out to 100 miles. Prior to the war, more than 1,000 PRC-112s were bought for SOF and Navy troops. Although the Air Force had not bought any before the war, they realized their mistake, and the director of operations for CENTAF sent a message to the Pentagon asking for several hundred radios for aircrews and homing receiver-modification kits to equip more helicopters. The MH-53 and Navy HH-60 were already modified.[53]

Interestingly, the message did not ask for modification kits for any fighter aircraft—not the F-15s or even the A-10s assigned to rescue-support duty. Perhaps an even better choice would have been the 72 block-40 F-16 C/Ds, which were being used in the war and were equipped with integrated GPS navigation systems. Modified with that homing gear, they could locate survivors by locking their sensors on the survivor's PRC-112 transponder. Their navigation system would then determine the precise GPS coordinates of the downed aircrew's location, which they could pass to the MH-53s.[54]

Although never explicitly stated, it seems that those aircraft were needed for other missions—hunting Scuds and destroying the Republican Guard divisions. As incredible as it seems, the availability of aircraft was incredibly tight. One scheduler noted that "with all the aircraft available in theater, I found it difficult to believe that we were actually 'short' [of available aircraft to strike the Scud sites]. We did, however, have that problem. With the number of packages and individual missions scheduled in the ATO, there are, in fact, very few unscheduled aircraft available."[55]

Colonel Ruth and his men were ready to fly. However, unlike in the Vietnam War, where almost-unlimited sorties were available to service very few important targets, there were limits on the number of sorties that could be produced during Desert Storm, and almost every sortie had a designated target that was a critical part of the campaign plan.

Like the F-111 crew 19 years before, Colonel Eberly and Major Griffith had not been rescued. In both cases, the aircrews had been shot down in high-threat areas, and a combination of factors had combined to prevent successful rescues. Nevertheless, rescue forces had made the effort and kept faith with their motto, "These things we do so that others may live." □

Notes

1. Chris Hobson, *Vietnam Air Losses* (Hinkley, England: Midland Publishing, 2001), 244; and Col Jerry Shipman, USAF, retired, interview by the author, June 13, 2002.

2. David W. "Dave" Eberly, e-mail to author, April 14, 2002.

3. Rick Atkinson, *Crusade: The Untold Story of the Persian Gulf War* (Boston: Houghton Mifflin, 1993), 126.

4. Ibid.

5. Michael R. Gordon and Gen Bernard E. Trainor, *The Generals' War: The Inside Story of the Conflict in the Gulf* (New York: Little, Brown, 1994), 250.

6. Brig Gen George Gray, USAF, retired (former commander of the 1st SOW), interview by the author, May 3, 2001; and *United States Special Operations Command History*, HQ USSOCOM/SOCS-HO, MacDill AFB, FL, November 1999, 36.

7. ICAO Circular 185-AN/121, *Satellite Aided Search and Rescue–The COPAS SARSAT System* (Montreal: International Civil Aeronautical Organization, 1986), 17; Brig Gen Rich Comer, interview by the author, July 19, 2000; and Supporting Document I-79, *US Air Force Rescue Force Structure Plan*, September 22, 1989.

8. Lt Col Joe Hampton (former director of the JRCC), interview by the author, March 21, 2000.

9. Ibid.

10. United States Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress* (Washington, DC: Department of Defense, April 1992), 177.

11. Gray, interview.

12. Lt Col Matt Shozda (Harden's MH-53 copilot), interview by the author, September 12, 2002.

13. Gordon and Trainor, *The Generals' War*, 258.

14. Lt Col Randy O'Boyle (MH-53 pilot assigned to the TACC), interview by the author, March 20, 2000; Hampton, interview; and Comer, interview.

15. Gordon and Trainor, *The Generals' War*, 258.

16. Time Sequence for CSAR, Corvette 03 SAR, and assorted notes. Desert Storm Box no. 2, Joint Personnel Recovery Agency, Fort Belvoir, VA.

17. Ibid.

18. Lt Col Pete Harvell (CENTCOM staff officer in the J-3 recovery section), interview by the author, January 29, 2002.

19. O'Boyle, interview.

20. Col Ben Orrell, USAF, retired (1st SOW's director of operations and combat rescue expert), interview by the author, January 17, 2002.

21. Col Bob Ruth, USAF, retired (assistant director of operations, 4th TFW), interview by the author, March 24, 2001.

22. Ibid.

23. Col Ed Houle, USAF, retired (commander, 10th TFS), interview by the author, March 28, 2001.

24. Time Sequence for Corvette 03.

25. Ibid.

26. William L. Smallwood, *Strike Eagle* (Washington, DC: Brassey's, 1994), 124.

27. Ibid., 123.

28. Hampton, interview.

29. Smallwood, *Strike Eagle*, 124.

30. O'Boyle, interview.

31. Hampton, interview. DF is an acronym for direction finding.

32. Lt Col Steve Otto (MH-53 pilot during rescue attempt), interview by the author, April 30, 2001.

33. Otto, interview. ISOPREP is the acronym for the "isolated personnel report" that documents unique information on an aircrew to allow for positive identification during a search-and-rescue operation.

34. Ibid.

35. Benjamin Schemmer, "No USAF Combat Rescue in Gulf; It Took 72 Hours to Launch One Rescue," *Armed Forces International*, July 1991, 37.

36. Gordon and Trainor, *The Generals' War*, 259.

37. Hampton, interview.

38. Gordon and Trainor, *The Generals' War*, 260; and History, 4th TFW, January–December 1991, 77.

39. Shozda, interview.

40. Gordon and Trainor, *The Generals' War*, 261; and Otto, interview.

41. Lt Col Grant Harden (MH-53 pilot during rescue attempt), interview by the author, May 2, 2001.

42. Brig Gen Dale Stovall, USAF, retired (vice commander, AFSOC), interview by the author, September 3, 2001.

43. Harden, interview.

44. Otto, interview; and Harden, interview.

45. Shozda, interview.

46. Otto, interview.

47. Ruth, interview.

48. Tom Clancy with Gen Chuck Horner, *Every Man a Tiger* (New York: Putnam, 1999), 410.

49. Smallwood, *Strike Eagle*, 123.

50. Lt Gen Buster Glosson (director of operations, CENTAF), interview by the author, September 25, 2002.

51. Gray, interview.

52. Harvell, interview.

53. Gordon and Trainor, *The Generals' War*, 262.

54. Stan Morse, *Gulf Air War Debrief* (London: Aerospace Publishing Ltd., 1991), 194.

55. Williamson Murray with Wayne Thompson, *Air War in the Persian Gulf* (Baltimore: The Nautical and Aviation Publishing Company of America, 1996), 172.

Jayhawk! The VII Corps in the Persian Gulf War by Stephen A. Bourque. Center of Military History (http://www.army.mil/cmh-pg), 103 Third Avenue, Fort Lesley J. McNair, Washington, DC 20319-5058, 2002, 528 pages, $52.00 (softcover).

We airmen sometimes play down the roles of other services in joint missions. The dazzling display of airpower during Operation Desert Storm drew much attention to the stealthy F-117, the plucky A-10, and the veteran B-52. To be sure, the Army basked in the praise directed at the capabilities of the M-1 Abrams tank and the M-2/M-3 Bradley fighting vehicles, and the high-mobility multipurpose wheeled vehicle (HMMWV) became the darling of several civilian new-car lots. Despite all that praise and backslapping, one never truly appreciates the trip "there" unless one has a common frame of reference. Enter Stephen A. Bourque's historical coverage of the Army's VII Corps in the Gulf War. Bourque sits the reader right next to key VII Corps leaders, providing firsthand impressions and views of events on the front and in the tactical operations centers of the corps, division, and brigade.

Most striking about this book is its ease of reading. One doesn't have to be an expert on Army doctrine, tactics, and jargon to appreciate *Jayhawk!* The author does a fantastic job of walking the reader through some VII Corps history, background of deployment exercises, and evolution of AirLand Battle doctrine before launching into the record of the corps's deployment and combat operations.

And what a read it is! Unless people have "been there, done that," they can't fully appreciate the scale and complexities involved in assembling, moving, and controlling 145,000 moving parts (i.e., individual soldiers) and supporting equipment. Bourque guides us step-by-step through receiving the initial notification, preparing for deployment, deploying and arriving in-theater, moving to assembly areas, and finally jumping off to war into Iraq.

My deployment exercises and operational experiences with the 1st, 3d, and 5th Infantry Divisions, US Army Europe, and with the 12th Aviation Brigade all helped color my reading of *Jayhawk!* Bourque hits it dead-on, capturing in great detail the steps individual soldiers must take to prepare and deploy equipment. Moving an Air Force combat wing is nothing like moving an Army brigade. His commentaries on the trials and tribulations of the corps's senior leadership help bring a human side to what can easily seem an impersonal deployment machine.

But it's not until VII Corps launches into Iraq that the reader fully appreciates what its troops went through. For these soldiers, the 100-hour war was just that: 100+ hours, perhaps with an hour or two of sleep, of enduring the sharp staccato of combat in seemingly endless seas of sand. Bourque clearly tells the reader that the "Desert war in 1991 was not the clean, high-technology conflict portrayed by the news media. It was dirty, confusing, and bloody" (p. 315). He also investigates breakdowns in communication and staff actions as fatigue finally takes hold at the end of the ground action (p. 380). Few airmen can fathom a mission lasting more than 30 hours, during which a stop at the club, a shower, and a few hours' rest may await the combatants; for VII Corps's soldiers, few had more than a catnap while they slogged forward each day in some of the wettest weather Iraq had to offer from February 23 to March 1, 1991.

Naturally, Bourque trumpets the outstanding capabilities of the Army's equipment, the soldiers' training and leadership, and the ways that this synergy overcame a capable foe. Time and again, he digs into historical records to dispel the impression that the Iraqi army just put down its weapons and surrendered. On the contrary, at times—such as the Battle of 73 Easting (pp. 325–44)—the Iraqi army put up a formidable defense. If the Iraqis had been better prepared through training and leadership, the toll in coalition lives may have been significantly higher.

Using combat records, Bourque also questions airpower's effectiveness against Iraqi tactical units, tossing aside the Air Force's claim that airpower won the Gulf War. Although he does not discount the Air Force's participation (the A-10 was an aircraft the Iraqi army didn't like to see), Bourque points out that several Republican Guard units—one of the key targets of the Gulf War—moved without much, if any, interdiction from the air during the entire war. In fact some units were at or above 70 percent of their effective strength when they engaged VII Corps at the start of the Battle of 73 Easting. It was the corps's soldiers who ultimately destroyed several of these units. According to an Iraqi battalion commander from the Tawakalna Republican Guard Division, "When the air operations started, I had 39 tanks. After 38 days of the air battle, I had 32 tanks. After 20 minutes against the 2nd Armored Cavalry Regiment, I had zero tanks" (p. 364).

Indeed, citing VII Corps's records, Bourque points out that although the Iraqi army feared the A-10 and B-52, they were in shock over the Apache helicopter. Negotiations to hold the cease-fire talks at Safwan Airfield nearly came to a standstill until a flight of Apache helicopters flew low overhead during the discussions. The Iraqi delegation quickly agreed to terms for the cease-fire site, knowing from very recent experience that a flight of four Apaches could destroy an entire battalion of Iraqi armor in minutes (p. 403).

I have only two criticisms of this book. First, Bourque glosses over the psychological effects of the previous four weeks of aerial bombardment. Some of the Republican Guard units were relatively unaffected, but other frontline forces had been beaten up by air attacks and were not effective in countering the American ground forces. Overwhelming ground-combat power may have administered the finishing blow, but many of these frontline Iraqi troops were ready to give up, seemingly firing only token shots of resistance so they could surrender with honor. Second, although it was not incumbent upon Bourque to address other American and coalition ground operations, one may get the impression that VII Corps won the Gulf War by itself. *Jayhawk!* is an excellent story of VII Corps in the war, touching on the progress of other units as the tale unfolds. But the reader must keep in mind that VII Corps was indeed an important chess piece—but only one of several on General Schwarzkopf's sandy chessboard.

I strongly recommend *Jayhawk!* as a must-read for all airmen, especially those whose jobs take them to work with Army units. Bourque captures valuable combat lessons and illustrates the fine tether that holds command relationships together. Finally, he reminds us that even in these days of push-button technology, ground war will still be dirty, confusing, and bloody. We all would do well to march a day in these combat boots.

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The *Liberty* Incident: The 1967 Israeli Attack on the U.S. Navy Spy Ship by A. Jay Cristol. Brassey's, Inc. (http://www.brasseysinc.com/Books/157488414X.htm), 22841 Quicksilver Drive, Dulles, Virginia 20166, 2002, 320 pages, $27.50 (hardcover), $18.95 (softcover).

On June 8, 1967, aircraft and torpedo boats of the Israeli Defense Forces (IDF) struck the USS *Liberty*, a small warship, also known as a "spy ship," that collected signals intelligence for evaluation by the National Security Agency (NSA). A US Navy crew operated the ship, and NSA employees collected the electronic signals. The ship had been ordered to monitor signals in the eastern Mediterranean, but, when war broke out between Israel and its Arab neighbors on June 5, the Navy sent five messages to the *Liberty*, ordering it to stay out of the now-hostile waters off Egypt and Israel. Unfortunately, only one of these messages reached the *Liberty*—and that one arrived 30 minutes after the attack. As the ship reached its designated listening post, Headquarters IDF had received reports of an Egyptian warship shelling Israeli positions along the Sinai coast. The two events now became cloaked in Clausewitz's "fog of war," combining to produce the tragic attack that killed 34 Americans and wounded 171 others aboard the ill-fated ship.

Since then, great controversy has surrounded the Israeli attack on the USS *Liberty*. Did the Israelis deliberately attack a warship of their best and only friend in 1967? Did the governments of both the United States and Israel deliberately cover up the attack? Have investigations by both governments whitewashed the incident for some secret national-security reason? Did Moshe Dayan, the war hero of previous Israeli-Arab conflicts and the minister of defense in 1967, personally order the attack? These and other questions have haunted this tragic occurrence for the past 35 years. This most recent addition to the historiography of the *Liberty* incident is probably the most comprehensive and unbiased account of this event and has the potential to put these questions to rest.

A former naval aviator and currently a federal judge, Dr. Jay Cristol is uniquely qualified to examine the Israeli attack on the *Liberty*. He brings his personal experience as a flyer and his professional skills as a legal expert to bear in reviewing all the available evidence. For 14 years, he examined investigation reports of various US government commissions and Israeli investigations, the testimony of *Liberty* crew members, recently unclassified documents, and Israeli audiotapes of the attack. Additionally, he conducted interviews with key, high-ranking American and Israeli officials and several former members of the *Liberty*'s crew. He weaves this wealth of information into a highly readable and persuasive narrative.

The author carefully examines the conspiracy theories and tall tales that sprang up in the wake of the attack and that have continued to thrive, despite all the evidence to the contrary. For years, various people, including several crew members of the *Liberty*, have persisted in propagating the theory that the Israelis deliberately attacked the ship and that the two governments covered up the incident for some nefarious reason. These individuals have consistently debunked the findings of the many investigations conducted by the US Navy, US Congress, and the Israeli government. Cristol carefully examines all the extant evidence, concluding that the IDF did not deliberately attack the *Liberty* and that neither government tried to cover up the incident. Although some reports were classified, most were not and have been available to citizens who sought them. Virtually all of the formerly classified reports are now readily available. Through his careful, detailed, documented, and objective analysis of these reports and information from other sources, the author persuasively counters the conspiracy theories and tales.

After completing Cristol's book, the truly objective reader should reach the same conclusions as did the numerous investigations and the author—that the tragic attack on the *Liberty* was a grievous case of mistaken identity and nothing more. Killing and injuring friendly forces have always been unfortunate consequences of war—witness the fatal shooting of Gen Stonewall Jackson in 1863 by his own troops at Chancellorsville, Virginia; the Eighth Air Force bombing of American troops at Saint-Lô, France, in 1944; and the shootdown of two US Army Black Hawk helicopters in Iraq by two US Air Force F-15s in April 1994. Furthermore, both governments made complete and honest investigations to determine the causes of the incident. If anything, the US Navy should shoulder the preponderance of responsibility for the attack because its inadequate communications system of 1967 failed to give the *Liberty* timely notice to stay away from the war zone—if it had not been there in the first place, it would not have been attacked. This book should put to bed the notions of a deliberate Israeli attack and cover-up. Unfortunately, human nature being what it is, some people will continue to believe these ideas. Hopefully, this book will persuade others that the attack on the *Liberty* was truly a case of mistaken identity.

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Malta Spitfire: The Diary of a Fighter Pilot by George Beurling and Leslie Roberts. Stackpole Books (http://www.stackpolebooks.com), 5067 Ritter Road, Mechanicsburg, Pennsylvania 17055-6921, 2002, 260 pages, $19.95 (softcover).

Critics often look at movies like *Casablanca* and say, "They sure don't make them like that any more." Similarly, aviation nuts like me swoon when they see a P-51 Mustang or Spitfire fly overhead, declaring, "They sure don't make planes like that any more." In the world of military history books, the memoir occupies a special niche because its tone and sense of urgency make it unique and interesting to read: "They don't write books like this any more."

Originally published in 1943, *Malta Spitfire* chronicles the flying career of a superior Canadian fighter pilot who rose to fame and notoriety over the skies of Malta in the summer of 1942. His record of destroying 27 German and Italian aircraft, damaging eight others, and scoring three probable kills in a 14-day period stands as one of World War II's memorable aerial-combat achievements. Impressive though these numbers may be, it is his account of learning to fly, trying to join the Royal Canadian Air Force, and fighting the Luftwaffe as a Royal Air Force pilot that makes this story so interesting.

Although sometimes labeled a cold-blooded killer, Beurling was more accurately a frustrated, desperate man whose hatred for the enemy is reflected throughout the book in his vitriolic, disparaging remarks about the Germans. Such emotions are difficult to imitate and can come only from the pen of someone intimately involved in this type of conflict. Beurling's explosive personality, however, often got him in trouble with his superiors—so much so, that even with 31 confirmed aerial victories and even at the height of the war in October 1944, the Canadians allowed Beurling to "retire" from military duty.

In addition to its ample illustrations and 12 black-and-white photographs, the book features a wonderful foreword and minibiographies of Beurling's fellow pilots by noted historian Christopher Shores. As with many memoirs, the writer often does not provide historical context, but that is no obstacle to readers who want to understand the thoughts and read the words of men embroiled in combat. Beurling and his squadron's contribution to beating back the German and Italian "blitz" of Malta and his expertise as a fighter pilot and master of deflection shooting make this story worth reading.

The study of battles and accumulation of detailed knowledge about aircraft obviously have their place in historical analysis. Too often, however, we tend to ignore the human element of warfare—yet another reason to read this book. Although $19.95 may be a bit steep for a paperback, *Malta Spitfire* will not disappoint its readers.

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On Target: Organizing and Executing the Strategic Air Campaign against Iraq by Richard G. Davis. Air Force History and Museums Program (http://www.airforcehistory.hq.af.mil/publications.htm), 200 McChord Street, Box 94, Bolling AFB, Washington, DC 20332-1111, 2002, 385 pages, $45.00. Available online at http://www.airforcehistory.hq.af.mil/Publications/fulltext/OnTarget(Davis).pdf.

On Target is a stunningly well documented and detailed book on Operation Desert Storm's strategic air campaign. Readers may wonder, however, "Since we just finished the second Gulf War, why read about the first?" In light of the success of Operation Iraqi Freedom, *On Target* provides a worthwhile read for air and space power professionals of all services as well as military-strategy enthusiasts as they prepare to delve into analyses of the more recent conflict. After all, one can't hope to understand Iraqi Freedom without understanding Desert Storm. Moreover, this book's surprising depth and detail make it well worth the effort.

In the book's Desert Shield section, reminiscent of Richard T. Reynolds's excellent *Heart of the Storm: The Genesis of the Air Campaign against Iraq*, published by Air University Press, Davis effectively presents both the situation in Iraq before the war and the convoluted planning process and backroom discussions that resulted in the air campaign plan. Dr. Davis's easy-to-read style captures many of the machinations of briefings and command personalities that play into campaign planning. He concisely and evenhandedly discusses John Warden's revolutionary concepts and Maj Gen Dave Deptula's construction of a master air-attack plan under Gen Buster C. Glosson and Gen Charles A. Horner, as well as the many interactions and conflicts between planners and commanders. The fact that he interviewed many of the principal players adds to the veracity of the account.

Although other books, such as Michael R. Gordon and Bernard E. Trainor's classic *The Generals' War: The Inside Story of the Conflict in the Gulf,* discuss the major political players in more detail, *On Target* expounds upon the intrigue and philosophies behind the emotions of warriors who debated how best to use the air component in this transitional war. Davis also adroitly mixes in operational details—who went where and when—during the initial confusion from deployment to combat.

In the Desert Storm section, Dr. Davis goes two steps further than most authors in terms of documentation and depth. For example, he even cites mission reports from the 4th Fighter Wing (Provisional), commanded by Hal Hornburg, a colonel at that time. Although his fleshing out of a few details leaves some gaps, Davis goes through the target sets selected by planners for attacks designed to bring Saddam Hussein to his knees in 1991. Thomas A. Keaney and Eliot A. Cohen's *Gulf War Air Power Survey* offers more statistics, but Davis's unclassified recounting covers most of the key points behind the air campaign plan. Initially called Instant Thunder, the strategic air campaign for Desert Storm was based upon Col John Warden's famous "five rings" theory for the application of strategic airpower. Many readers, however, will prefer the brief but rich stories of battle that tie the theory to combat action.

Although *On Target* is a bold addition to the history of war-fighting strategy, it suffers from two deficiencies. First, it gives short shrift to effects-based operations, which represent a critical departure from the AirLand Battle doctrine of the Cold War. The success of the Desert Storm air campaign helped make effects-based theory palatable to old-school ground-power strategists, and the joint world now considers such thinking standard.

Dr. Davis treats the story of the theory's development better than he does in the postwar assessment. Maj Gen David A. Deptula's monograph *Firing for Effect: Change in the Nature of Warfare* provides a simpler explanation of how and why we use effects-based operations—an evolutionary leap in planning that, together with our new precision-strike capabilities, allowed coalition air and space power in conjunction with only cavalry and special operations to crush the Taliban regime in Afghanistan and then support conventional forces in the march to Baghdad 18 months later. These hugely different operations shared a theory that enabled the same platforms and warriors to succeed in both cases. Flexibility is indeed the key to airpower.

Davis comments that "it is difficult to conceive of any bombing plan that will release the grasp of a police state on its populace" (p. 317). But as General Deptula writes, the goal of effects-based operations is "control," not simple attrition. Moreover, modern air and space power strategists don't plan to win wars through aerial bombardment alone—that idea went out with Billy Mitchell. On the other hand, perhaps Operation Allied Force and Slobodan Milosevic demonstrated that we should never say "never."

Second, examining the desired effects is critical to effective campaign planning—not shooting for a specific body count or a magic number of tanks destroyed. So it's important to remember that what many people traditionally think of as tactical targets—convoys, troops, and old-fashioned interdiction and close-air-support targets—can (and often do) yield strategic effects. The highway leading north from Kuwait City is a case in point. On February 26–27, 1991, F-15Es, A-10s, and a host of other coalition aircraft wreaked havoc on the Iraqi army's armed retreat. Dr. Davis doesn't even mention this event, even though other sources point to it as a key reason that some allied leaders sought a quick end to the ground campaign. Strategic target sets are critical, but effects can cause unintended consequences that ripple far beyond the battlefield.

I'm not sure that I buy the author's conclusion that "the strategic bombing campaign against Iraq was *a* decisive factor. . . . When joined to the tactical air effort against Iraqi forces in Kuwait . . . air power was *the* decisive factor" (p. 320, emphasis in original). I strongly feel that the "which is more decisive" debate is both futile and tired. Yet, this criticism doesn't take away from the fine scholarly effort by Dr. Davis, who has a gift for capturing a wildly complicated plan and making sense of it on paper. Furthermore, his documentation and level of specificity are outstanding. Many unique sources, including mission reports that probably only aircrews and intelligence officers have read, are available to the average reader solely through this book. I also like *On Target* because it may set young and old warriors alike to thinking about *why* we do *what* we do—and *how* we do it.

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Secret Intelligence in the Twentieth Century edited by Heike Bungert, Jan Heitmann, and Michael Wala. Frank Cass Publishers (http://www.frankcass.com), 5824 NE Hassalo Street, Portland, Oregon 97213-3644, 2003, 200 pages, $84.95 (hardcover).

Since the fall of the Berlin Wall and the opening of archives in the former East Germany, a torrent of information has appeared in the popular press. The scholastic approach of *Secret Intelligence in the Twentieth Century* examines German intelligence structures and policy as well as the attempts of other powers to gather intelligence about German states. Some of the early essays in the book cover issues already known to most intelligence researchers, but one also finds real gems dealt with for the first time in print. An account of the attempted use of ethnic Germans during World War II makes for interesting reading, for example. What makes this book unique, however, are the post–World War II pieces, such as the one that addresses the ability of Gen Reinhard Gehlen of Fremde Heere Ost, one of the intelligence arms of the German High Command, to foresee the demise of the World War II–era Anglo-Soviet bond and Germany's emergence as a vital part of the Western defense alliance. Not only does one find details concerning Gehlen's influence on German national-security making and policy development, but also information about his ties to the CIA and the US Army's G-2 in Heidelberg. A KGB officer's viewpoint of KGB and East German penetration of the Gehlen organization and its successor, the BND (German Intelligence), makes the whole period come alive. The establishment of East German security services and their role in the East-West spy game show that the Soviets were intimidated by Gehlen's successes but that the KGB also lacked the skills to be successful in a Western-oriented Germany.

For Air Force readers, the essay on the Wringer Project is the first entry in what undoubtedly will become a new subfield in East-West Cold War history: the use of German former prisoners of war and detainees to build an intelligence and target database on the closed Soviet Union. Run by the Air Force to gather target data, Wringer showed the feasibility and indispensablity of the mass exploitation of human intelligence sources. The inability of the United States to obtain a good intelligence picture of events inside East Germany, especially during the 1953 revolt, may have led to policy decisions in Washington that ultimately caused the uprising to fail. West Berlin, the island inside East German territory, proved a valuable listening and observation point for the CIA in the early years of the Cold War. The book includes accounts of the experiences and successes of former agents in charge there.

Because of the scarcity of intelligence texts, any contribution to the field is welcome, especially one that covers Germany and the early Cold War. *Secret Intelligence in the Twentieth Century* contains much of interest to both Air Force historians and intelligence historians.

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Corporate Warriors: The Rise of the Privatized Military Industry by P. W. Singer. Cornell Studies in Security Affairs, Cornell University Press (http://www.cornellpress.cornell.edu), Sage House, 512 East State Street, Ithaca, New York 14850, 2003, 352 pages, $39.95 (hardcover).

In the past 10 years, in the aftermath of the Cold War, military forces and military budgets have become smaller. The superpower standoff has disappeared, allowing former client states to engage in internal and external wars with impunity. Wars are more frequent, and those who would intervene have less capacity to do so. Militaries are also trying to maximize tooth and minimize tail. Filling all the gaps are corporate warriors, private armies willing to go anywhere and do almost anything—for a price.

P. W. Singer traces the history of mercenaries and other private forces, noting that the tradition is as old as civilization—beginning in Ur thousands of years ago. Given that the "modern" national state military dates back only 200 years, the privatized military industry (PMI) is not the departure from tradition that it first seems. But PMIs are not purely mercenaries. They come in three general types: providers, consultants, and support services. Executive Outcomes was a provider (i.e., a combat force). Consultants are more accurately designated military advisors and trainers; for example, Military Professional Resources Incorporated (MPRI), a spin-off from the Lockheed-Loral merger, built the Croat army. A representative support PMI is Brown & Root Services, the Halliburton subsidiary that is currently a major contract rebuilder in Iraq.

PMIs are problematic. For one thing, the commander loses disciplinary control over contract employees; the penalty for breach of contract differs greatly from that for being absent without leave. For another, the fact that these companies generally have cost-plus contracts and proprietary information makes it hard to determine whether or not the PMI is really providing the right service. In the worst case, governments can lose the ability to handle their own defense. Furthermore, there is reason to worry about the implications for nation-states in a world of extremely well armed global corporations.

Corporate Warriors breaks new ground as the first serious study of a decade-old phenomenon that evolves with each merger and absorption of the PMI into a global conglomerate. It should be required reading for military professionals and anyone else concerned about the unfolding of our American experiment in civilian control of the military and the state control of force.

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Space Policy in the 21st Century edited by W. Henry Lambright. Johns Hopkins University Press (http://www.press.jhu.edu), 2715 North Charles Street, Baltimore, Maryland 21218, 2003, 272 pages, $49.95 (hardcover).

Space Policy in the 21st Century is not really about space policy in the twenty-first century. It is about a far more specialized topic—*civil* space (i.e., the National Aeronautics and Space Administration [NASA])—in an increasingly distant (in substance as well as time) era: the end of the twentieth century. Although the book carries a copyright date of 2003, it is clear that the writing of its nine articles predates two important events in the national space arena: (1) September 11, 2001, and (2) the loss of space shuttle *Columbia* on February 1, 2003. This combination of too narrow a scope and a focus on yesterday's issues serves to make this collection more historical artifact than useful guide to contemporary national space policy.

The book's primary shortcoming is its almost exclusive focus on civil space; it gives short shrift to commercial space ventures and virtually no attention to national-security space activities. This is particularly frustrating in the post-9/11 and post-*Columbia* environment. This book treats NASA and its missions as the *centerpiece* of national space policy, whereas a central issue in today's broader space-policy circles is, indeed, the very *relevance* of NASA, which finds itself on the verge of being squeezed out between commercial endeavors on the one side and national-security pursuits on the other.

The global positioning system is a case in point. This technological wonder that enables precision warfare and also provides the bedrock for civil navigation and even financial transactions worldwide receives minuscule attention here. Similarly, the Evolved Expendable Launch Vehicle program, which saw two successful maiden flights by separate launch providers in 2002 and which may be (in the post-*Columbia* era) man-rated for NASA missions in the years to come, is not even mentioned in the chapter on "Space Access." Even more surreal is Ronald J. Deibert's claim in his chapter regarding future uses for remote sensing that "the one [use] that is likely to generate the greatest need for satellite monitoring technologies in decades to come is studies of global warming and climate change" (p. 97). If only, in the post-9/11 world, this could truly be our greatest information-collection need!

Ironically, the chapters least anachronized by 9/11 and *Columbia* are those that would likely have been considered most fanciful at the turn of this century (e.g., Daniel H. Deudney's treatise on asteroid utilization and avoidance and Christopher F. Chyba's discussion of the search for extraterrestrial life). The book winds up with commentaries by John M. Logsdon and Howard E. McCurdy; these relatively skeptical assessments on the future of NASA programs, also somewhat dated, at least seem prescient in their cautionary themes.

Even in the late twentieth century, NASA could hardly be considered the solitary leader of national space policy; this truth is only more pronounced in the aftermath of 9/11 and *Columbia*. Despite the wishful thinking that runs in torrents through these pages, the real space-policy questions, for the foreseeable future, will address partnering by the Department of Defense (DOD)/NASA/industry to attain assured access, employing space capabilities to meet national-security needs, and strengthening space industry. Such questions will include the following: How can the DOD and NASA best partner to develop true assured access to space? What balance of regulation of commercial space activities will preserve security (both national and industrial) while maximizing commercial growth and investment? What are the proper technology road maps to produce space capabilities that will meet future national-security needs, future commercial-infrastructure demands, and space-exploration objectives? Readers looking for possible answers to these contemporary questions will not find them in this book. What they will find is history: musings on the future of NASA from a more lighthearted era.

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Der Brand: Deutschland im Bombenkrieg, 1940–1945 by Jörg Friedrich. Propyläen Verlag (http://www.propylaeen-verlag.de), Bayerstrasse 71-73, 80335 Munich, Germany, 2002, 591 pages (hardcover), Euro [D] 25.00.*

For decades, mainstream German historians and authors have trod carefully when discussing German victims of the Combined Bomber Offensive lest they be accused of relativizing Germany's aggression and the Holocaust. Yet, for an entire generation of Germans, the World War II experience is intimately linked to childhood memories of air raids, nights spent in bomb shelters, and the flight from the cities to the countryside. Jörg Friedrich's *Der Brand* (The Fire), which appeared shortly before the acrimonious German-American debate concerning the use of force against Iraq, generated an unprecedented level of public interest about the civilian and cultural costs of the Allied urban-bombing campaign against Germany, with commentators frequently drawing upon Germany's experience in World War II to comment about the potential impact of an air campaign against Iraq. German historians, literati, and public intellectuals contributed reviews and newspaper commentaries

*A fuller version of this review, including notes to current literature, appeared online last year: Douglas Peifer, "Review of Jörg Friedrich, *Der Brand: Deutschland im Bombenkrieg, 1940–1945*," *H-German, H-Net Reviews*, November 2003, http://www.h-net.msu.edu/reviews/showrev.cgi?path=277121069229925. For additional reviews, links, and commentaries on Friedrich's book, see "World War II Bombing: Rethinking German Experiences," *H-German Forum*, http://www.h-net.org/~german/discuss/WWII_bombing/WWII-bombing_index.htm.

on the Allied air campaign against Germany from the perspective of the bombed. German television, the popular press, and the book industry capitalized on public interest by airing documentaries, publishing serials on the aerial destruction of Germany's cities in World War II, and spurring book sales on firebombing, bomb shelters, airpower, and civilian casualties. British historians joined the fray, with the British popular press lambasting Friedrich's work and warning of German revisionism. Despite mixed reviews, *Der Brand* proved wildly successful in Germany because it addressed an issue where history, memory, and current security debates intersected—namely, the use and misuse of airpower.

Der Brand engendered this amount of attention and debate not because it unveiled startling new revelations or called for fundamental reinterpretations of the historical record, but because it touched several sensitive points of contention. First, the book is one of several in which the German Left has rediscovered events from the past that have never faded from the memory of the conservative Right: the German civilian casualties of the Anglo-American air campaign, the maritime evacuation of Germans from East Prussia, and the post–World War II expulsions of Germans from the Sudetenland, Poland, and elsewhere. The German Left's reacquisition of a portion of the memory spectrum, long voluntarily ceded to conservatives, has raised concern that Germans may embrace a cult of victimhood that relativizes Germany's role in the outbreak of war, in the implementation of the Holocaust, and in the Wehrmacht's deliberate violation of rules of warfare on the Eastern Front.

Second, the book has stirred interest because it tackles a long vein of scholarship on the issue of morality in war—specifically, a long-running debate about *jus in bello* criticisms of Allied area-bombardment strategies during World War II. The British reaction to Friedrich's work focuses on this issue, with the British boulevard press particularly enraged by the author's assertion that Churchill was responsible for the death of tens of thousands of innocent women and children. In addition, Friedrich correctly points out that from the ground perspective, the much-publicized contrast between British nighttime area bombardment and American high-altitude precision daylight bombing was often moot, with American bomber groups exacting a high casualty rate among civilians. Although Friedrich's analysis of the brutalization of the air war presents nothing new, his previous work examining Wehrmacht crimes and Nazi justice enables him to approach the subject without risking automatic dismissal as a right-wing apologist. For a German public sensitized to the distinction between legal and illegal conduct in war as a result of decades of scholarship on German war crimes, *Der Brand* offered the opportunity to broaden focus and subtly reengage German Nuremberg-era rebuttals of tu quoque (legal defense of "you did likewise").

Tied to this historical analysis of the morality of the Anglo-American air campaign against the Third Reich is a related third debate—namely, what lessons one can draw from the past that have current relevance and applicability. *Der Brand* was published in November 2002, shortly before the high-water mark of the Bush administration's effort to garner international support for the forcible removal of Saddam Hussein. German peace activists frequently proclaimed that history proved that force was not an answer, with commentators such as Hans Mommsen noting that no one should be surprised at the Germans' opposition to war, given their historical experience. Friedrich echoed similar sentiments elsewhere, commenting that since 1945 Germans have empathized more with the bombed than the bomber. Evidence linking sales of *Der Brand* to then-current discussions of war against Iraq is circumstantial, but numerous interviews make connections between the two, suggesting that the interaction among history, memory, and current affairs increased interest in and readership of *Der Brand*.

Despite all the attention it has garnered, Friedrich's 591-page work is problematic, approaching the subject in an impressionistic, suggestive manner that leaves the reader with a sense of unease. He divides his work into seven main parts, with the first two ("Weapons" and "Strategy") accounting for approximately a third of the book, the next section ("The Land") accounting for another third, and the final four parts ("Refuge," "We," "I," and "Stone") accounting for the final third. Throughout, he eschews traditional citation methods, simply listing his largely secondary sources for each page without the use of endnote numbers. His thematic approach tends to blur the chronological sequence of events, and his use of terminology deeply associated with the Holocaust and National Socialism (e.g., cellars as "crematoria," the Royal Air Force's 5th Bomber Group as an "Einsatzgruppe," cities as "execution sites," and the incidental destruction of libraries as "book burning") is deliberately provocative.

Friedrich's treatment of the weapons and strategy of the air campaign against Germany provides a fair introduction to the topic for nonmilitary historians and the public. He commences his work with a detached, technical discussion of the weapons and platforms that made a strategic-bombing campaign possible: explosive and incendiary bombs, long-range bombers, radar technology, and bomber crews. Moving to strategy, he traces the evolution of strategic air war from its World War I roots through the Combined Bomber Offensive against Germany, although his propensity to move back and forth in time and his conflation of strategic and tactical air raids make it difficult to follow the overall evolution of the bombing campaign. Others have written better and more detailed analyses of weapons development and airpower strategies in World War II. What Friedrich does well, however, is to translate what these weapons and strategies meant to the citizens of Lübeck, Cologne, Hamburg, the Ruhr, Berlin, and some 158 midsize towns similar to Pforzheim, Würzburg, and the like. His imagery of women stuck in the melting tar of a street like flies on flypaper, of families recovering the charred remains of their loved ones in buckets, and of cellars baking their inhabitants alive is stirring and unforgettable. Friedrich writes in terms of images, experience, and emotion, providing graphic depictions of human suffering at the expense of a careful, chronological reconstruction of the air war against Germany.

He devotes over one-third of his study to discussion of the German land. Loosely following the chronology of an air campaign limited by range and front line, he first discusses air attacks on the cities of North Germany, then shifts to the West and the Ruhr attacks. He subsequently examines the fate of South German cities and ends his city-by-city examination with a discussion of Berlin and the East. Friedrich's approach is relentless and detailed: with each city or town, he presents a brief account of its history, heritage, and main cultural treasures before examining its demise and destruction. The entire section is marked with a sense of sadness and loss—not just for the miserable death of thousands of innocents, described in vivid and unrelenting specificity, but for a cultural loss that can never be restored.

The chapters on "Refuge" and "We" are the most intriguing sections of his study. In "Refuge" Friedrich describes the hierarchy of refuge (from blast trenches to cellars to elaborate bunkers), civil-defense measures, the recovery and disposal of bodies, and the state's role in aiding bombing victims and evacuating nonessential personnel from Germany's cities. Rather than driving a threatened population to revolt, the bombing of cities initially brought the people closer to the state. Using both positive and negative tools of persuasion, the same state that gave out buttered bread and soup to bombing-raid survivors was ready to ruthlessly execute plunderers and those who subverted the military spirit (*Wehrkraftzersetzer*). Friedrich develops this theme in greater detail in his discussion of the collective "We." He notes how as the situation worsened, the repressive state focused on the issue of *Haltung* (conduct) over *Stimmung* (morale). German propaganda emphasized grim perseverance, promising that wonder weapons would soon allow Germany to strike back at the Allies and exact a bloody revenge. Each of these topics has been treated in greater detail elsewhere, and Friedrich overlooks much of the most recent scholarship in German and English. Nonetheless, these sections succeed in laying bare the interaction between protection and repression in the individual/state relationship.

Der Brand's final two sections are less effective. In the chapter "I," Friedrich attempts to describe the individual's sensory and psychological reaction to bombardment. His discussion of the physical reaction of the body to extreme stress rests on a handful of books and memoirs, overlooking the wealth of literature on the related phenomenon of combat stress, war neurosis, and shell shock. In "Stone," Friedrich examines German efforts to rescue cultural sites, works of art, libraries, and archives. Placing this discussion at the end of the work, however, violates the book's overall framework of decreasing concentric rings (strategy, the land, refuge, we, I) and proves disconcerting by following several chapters devoted to group and individual suffering. The section would have been much more effective as part of Friedrich's earlier discussion on "The Land," which focused on history, heritage, and destruction.

Overall, *Der Brand* is an evocative book, heavy on imagery, eyewitness accounts, and impressions. Highly effective as a literary dirge and lamentation, it comes up short when judged by the standards of the history discipline. Friedrich blurs chronology, overlooks the newest scholarship on many of his topics, skims over the broader context in which the strategic air war developed, and employs terminology in a careless or deliberately provocative manner. Most troubling to historians will be his narrow focus and lack of context: although he briefly mentions Warsaw, Rotterdam, Coventry, and the Holocaust, they fade from view throughout much of the book as Friedrich examines German suffering and loss in unrelenting detail. The topic itself—the German experience at the receiving end of a prolonged and costly strategic-bombing campaign—is a valid and important area of historical inquiry that should not be taboo to German scholars. Indeed, a body of German scholarship does exist on the topic, ranging from detailed analyses of Freiburg, Münster, and numerous other German cities during the *Bombenkrieg* (the German term for the Allied aerial bombing campaign in World War II) to studies focusing on popular opinion, the evacuation of children, life in the bunker, flak helpers, and the mechanisms of relief and repression. One might even concede that some of the military history on the strategic-bombing campaign focuses too heavily on operations, aircraft, technologies, and the war in the air, with insufficient description of the human costs of war. Thus, Friedrich's work performs a valuable function of redirecting attention to war's terrible cost in lives, suffering, and cultural treasures. What makes one uneasy about the book is that it addresses only one dimension of the human aspect, focusing sharply on German loss but scarcely acknowledging the death and devastation that Germans inflicted on others during World War II.

Given these flaws, the prospect of *Der Brand*'s being translated into English appear dim. Yet, for those willing to make the effort, reading the piece is worthwhile. Friedrich's comment in one interview that since 1945 Germans have identified with the bombed rather than the bomber explains in part Germany's opposition to the war in Iraq. Overall, *Der Brand* is deeply moving as a literary work, troubling as a work of historical scholarship, and most useful as an illustration of the interplay among history, memory, and current affairs in present-day Germany.

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When Thunder Rolled: An F-105 Pilot over North Vietnam by Ed Rasimus. Smithsonian Institution Press (http://www.sipress.si.edu), 750 Ninth Street NW, Suite 4300, Washington, DC 20560-0950, 2003, 272 pages, $27.95 (hardcover).

One would have thought that the market for Vietnam air-war stories is saturated, but now I have another book to recommend to the professional air warrior. Not much in *When Thunder Rolled* is new: flying the Thunderchief in combat over North Vietnam in the mid-1960s was hazardous to one's health; the theory of gradualism wasted airmen's lives without having much impact on enemy decisions; and micromanagement of field leadership from afar had similar effects. Yet, Ed Rasimus manages all of that in an engaging way with readable prose and obvious pride in what he endured and achieved—but without the excessive chest thumping commonly found in such books.

Professor Rasimus, who now teaches political science in Colorado, claims to have been motivated in childhood by the romantic lure of aviation and airplanes. He tried to get in the Air Force Academy, but by the time he won an appointment, he was already a year into his AFROTC program—so he decided to stick with that. On entering the Air Force, he did well in pilot school, thus winning a choice assignment directly to what was then the Air Force's first-line fighter—the F-105. In his first tour as a second lieutenant, Rasimus served as a "Thud" pilot in the 388th Tactical Fighter Wing at Korat Royal Thai AFB, where he arrived in the spring of 1966 on the eve of the most fearsome part of the air war over Vietnam. After flying 100 missions, he came back to the United States in the fall.

In his book *Rise of the Fighter Generals*, Brig Gen Michael Worden emphasizes that the first flying tour, especially in combat, tends to have a formative effect on the mind-set of officers. If the general needed any more affirmation of this idea, Ed Rasimus could provide it. Rasimus does not pretend to be fearless, admitting to having grappled with genuine dread during his early missions and to doubts about his ability to continue. Yet he did carry on, even though electronic countermeasures and Wild Weasel defense-suppression units had not yet been developed to diminish the hazards he faced. Rasimus laments the loss of his flying buddies and speaks with admiration of the toughness and professionalism of rescue forces who, even then, were plucking some of them from the jaws of POW camps or worse. He even avoids the usual temptation to denigrate multiengine pilots retrained to fill the cockpits of lost warriors—a vice common among purebred fighter drivers. Yet, he *is* bold enough to condemn US leaders for placing at risk flights of multimillion-dollar airplanes against a few insignificant fuel drums and to call political leaders liars when they asserted that no bomb shortage existed in Vietnam.

However, one of the qualities that makes the book more engaging than the usual memoir is its use of the microview without pontificating about how somebody else lost the war. Rather, Rasimus effectively provides everyday details of life in flight operations and on the ground. I was not a fighter pilot, but I did follow him in the 388th Fighter Wing at Korat; I know from experience that those everyday details lend authenticity to the rest of the story and make it ring true for me.

One part of his life there that I could not share was the terror of flying against the most fearsome defensive system in history. Rasimus explains that at the end of the day, he had contained his fears and, unexpectedly, had come to enjoy the exhilaration of surviving a trip into the lion's den, likening the experience to youthful episodes of stealing hubcaps on the streets of Chicago. Vietnam seemed to produce the same kind of thrill, magnified many times over, that emerged from doing something essentially useless but potentially dangerous. It was a feeling that only a very few people could enjoy (either then or now). Certainly we can take him at his word—even having survived the first tour, in 1972 he volunteered to go back to participate in the last battle: Linebacker II.

Readers interested in air war at the operational, strategic, or political levels should take a look at Wayne Thompson's *To Hanoi and Back: The U.S. Air Force and North Vietnam, 1966–1973*. But for an enjoyable read on what combat is like for company-grade officers, I recommend *When Thunder Rolled.*

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Touch and Go

In this section of "Net Assessment," you will find additional reviews of aviation-related books and CD-ROMs but in a considerably briefer format than our usual offerings. We certainly don't mean to imply that these items are less worthy of your attention. On the contrary, our intention is to give you as many reviews of notable books and electronic publications as possible in a limited amount of space.

Fortress Ploesti: The Campaign to Destroy Hitler's Oil Supply by Jay A. Stout. Casemate Publishers (http://www.casematepublishing.com), 2114 Darby Road, Havertown, Pennsylvania 19083, 2003, 224 pages, $32.95 (hardcover).

Ploesti. The very mention of this area in Romania brings up visions of intense flak, nightmarish B-24 bombing raids, and a living hell. As a high school senior, I had a history teacher who had been wounded by flak over Ploesti. I remember his stories vividly.

Fortress Ploesti is not so much a recount of the operational aspect of the campaign as it is a collection of the experiences of people who lived through it. Although the author, Jay Stout, does discuss the mission background to some extent, the strength of his writing lies in relating what the combatants went through. Stout's research also included interviewing and examining the journals of German and Romanian military personnel who defended Ploesti. These sources clearly illustrate the determination and, in some cases, the desperation of these men as they faced wave after wave of bombers and their escorting fighters.

My advance copy needed more maps and pictures to illustrate Stout's points. Even without the additional illustrations, however, anyone generally familiar with the Ploesti campaign can easily follow the text. Readers looking for a book that covers the operational mission and details of the campaign plan to dismantle Ploesti will be disappointed, as will proponents of strategic bombing who want a broader discussion of Ploesti's role in the development of US strategic-bombing doctrine. But those of you who like to learn history and doctrine firsthand—from the people who lived through this harrowing campaign—should read this book.

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The Editor

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