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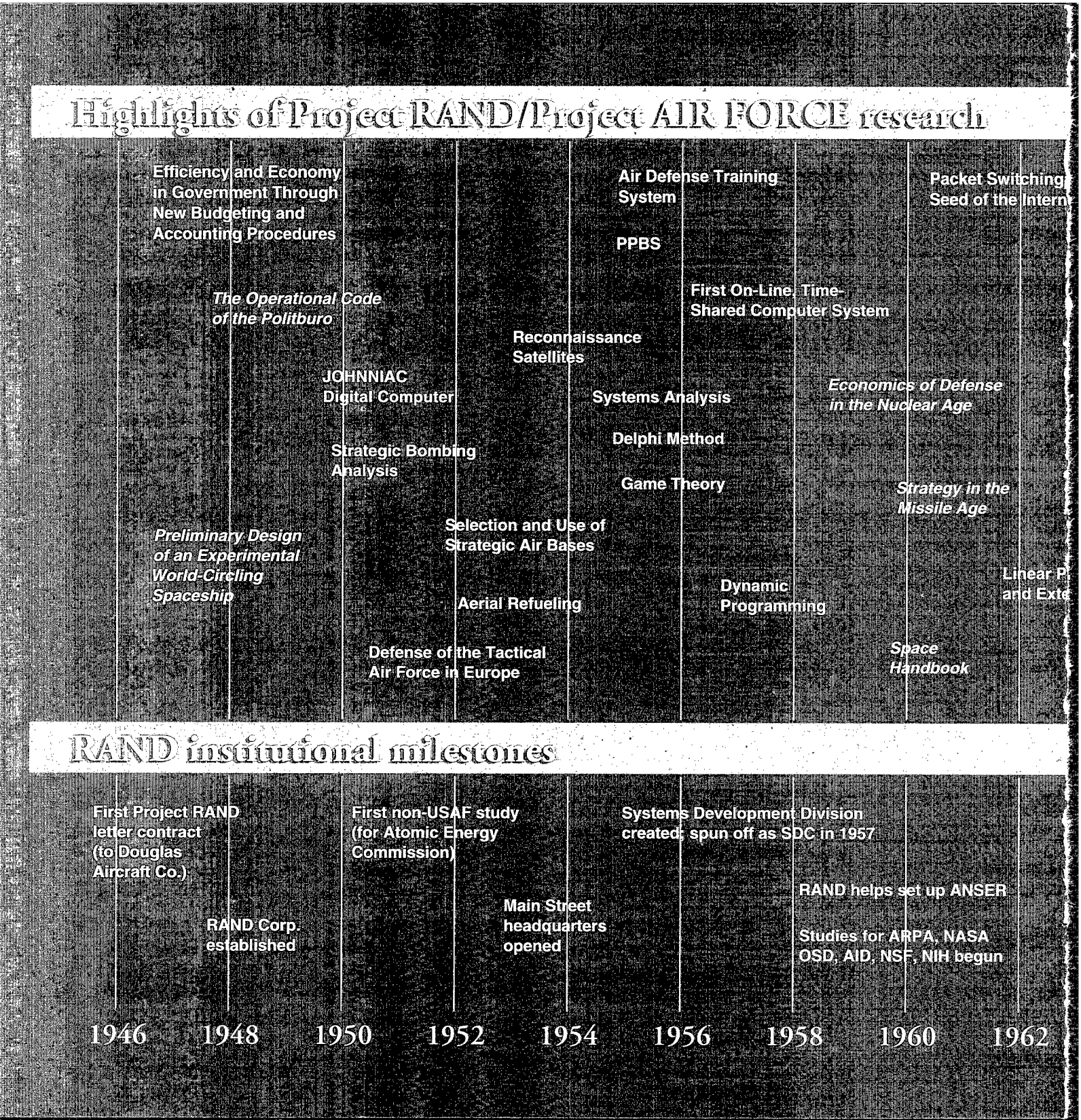
Highlights of Project RAND/Project AIR FORCE research
Efficiency and Economy in Government Through New Budgeting and Accounting Procedures
The Operational Code of the Politburo
Preliminary Design of an Experimental World-Circling Spaceship
JOHNNIAC Digital Computer
Strategic Bombing Analysis
Selection and Use of Strategic Air Bases
Aerial Refueling
Defense of the Tactical Air Force in Europe
Reconnaissance Satellites
Air Defense Training System
PPBS
Systems Analysis
Delphi Method
Game Theory
First On-Line, Time-Shared Computer System
Dynamic Programming
Economics of Defense in the Nuclear Age
Strategy in the Missile Age
Space Handbook
Packet Switching Seed of the Intern
Linear P and Exte
RAND institutional milestones
First Project RAND letter contract (to Douglas Aircraft Co.)
RAND Corp. established
First non-USAF study (for Atomic Energy Commission)
Main Street headquarters opened
Systems Development Division created; spun off as SDC in 1957
RAND helps set up ANSER
Studies for ARPA, NASA OSD, AID, NSF, NIH begun
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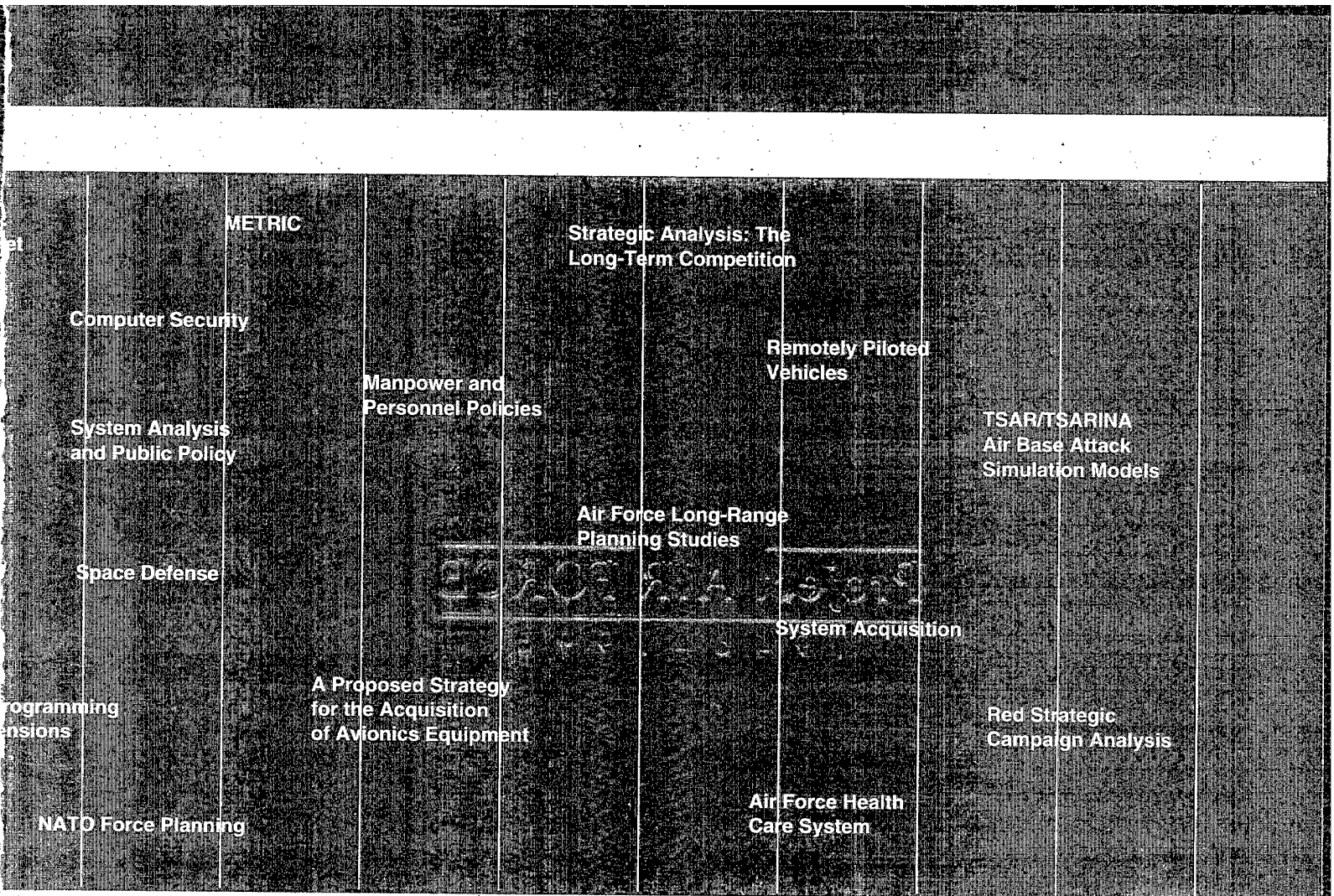
METRIC
Strategic Analysis: The Long-Term Competition
Computer Security
Remotely Piloted Vehicles
Manpower and Personnel Policies
System Analysis and Public Policy
TSAR/TSARINA Air Base Attack Simulation Models
Air Force Long-Range Planning Studies
Space Defense
System Acquisition
A Proposed Strategy for the Acquisition of Avionics Equipment
Red Strategic Campaign Analysis
NATO Force Planning
Air Force Health Care System
NYC-RAND Institute established; closed in 1975
Project RAND name changed to Project AIR FORCE
Domestic Research Division established
Washington Defense Research Division established
Institute for Civil Justice established
RAND Graduate School founded
National Security Research Division established
1964
1966
1968
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1972
1974
1976
1978
1980

50th

Project AIR FORCE

1946 - 1996

Photographs on p. 28 courtesy of the U.S. Air Force, Lockheed, and McDonnell-Douglas.
Most of the staff photographs were taken by J.R. "Goldy" Goldstein, associate director and vice president of The RAND Corporation in the 1950's and 1960's.

CONTENTS

A PARTNERSHIP OF TRUST

The 50th anniversary of Project AIR FORCE gives us a unique opportunity to reflect on past achievements and the legacy they provide for the future. The essays in this volume offer a montage of personal perspectives on that legacy. While they do not present a comprehensive history, they help us grasp the significance of our first 50 years.

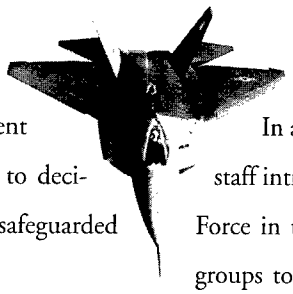
Readers of these essays may be struck by the sheer number of creative leaps taken by individuals working at Project RAND (1946–1976) and at Project AIR FORCE (1976–present). Some of those leaps led to developments that could not have been imagined when the work began. Who could have predicted, for example, that our research would help lay the foundation for the U.S. space program and for e-mail and the Internet? Or that our work in linear and dynamic programming in the late 1950s would become the heart of operations research as it is taught and practiced today? As we celebrate our 50-year mark, it is worth pondering the environment that made such creative work possible. What is it about the RAND partnership with the Air Force that fostered productive innovation and continued relevance over so many years?

Part of the answer lies in the revolutionary concept that was the basis for Project RAND. The founders—General of the Army H. H. "Hap" Arnold; MIT's Edward Bowles; Donald Douglas, Arthur Raymond, and Franklin Collbohm from Douglas Aircraft Company; and others—conceived of RAND as a way of retaining for the Air Force the considerable benefits of civilian scientific thinking that had just been demonstrated during World War II.

Their vision is reflected in a few enlightened principles:

- The new project's mandate was to be broad. It would cover nearly the full spectrum of Air Force concerns, including advice on broad policy issues, and would give special emphasis to long-term issues.

- RAND analysts were to work closely with the Air Force but remain independent from it. They would have ready access to decisionmakers, but their work would be safeguarded from service doctrine and advocacy.
- Perhaps most important, RAND itself was to determine, as much as possible, the subjects and the directions of its research.



From the vantage point of 1996, one of the most striking features of these principles is their spirit of trust. The founders believed that, given ready access to the Air Force at all levels and allowed maximum freedom to set and pursue research goals, RAND would produce invaluable results. Early dramatic successes, some described in these essays, quickly demonstrated the wisdom of this approach.

In the ensuing decades, the special relationship between RAND and the Air Force took many forms. RAND staff went to the factory, the depot, and the flightline to analyze logistics practices. They took active part in every Air Force long-range planning activity. They visited aircraft manufacturers to gather data on development programs and draw lessons that Air Force planners might use. At times, they assumed the role of educators, offering classroom instruction and writing textbooks on space technology, systems analysis, and cost analysis. In a less-formal version of the teaching role, RAND staff introduced the first computer technology to the Air Force in the 1960s, working with individuals and small groups to explore this revolutionary tool and lay out its various practical applications. Since the 1950s, the Air Force has also been a presence at RAND. Young officers—now called Air Force Fellows—joined our research teams in Santa Monica. They brought their operational experience to our work and learned how to apply multidisciplinary analysis to Air Force problems. Even more important, they actively helped acquaint RAND researchers with the reality of the Air Force, through talks and trips to Air Force bases.

In these joint efforts, the Air Force entrusted RAND with wide access to information about its operations, technology, intelligence, and plans. Yet, at the same time, the Air Force allowed RAND analysts to approach the issues in their own way. As a result, their findings and recommendations sometimes challenged prevailing thinking and interests. At times, the partnership of trust was strained, but it survived because experience had demonstrated to the Air Force the value of considering the unexpected, independent point of view.

The breadth of Project RAND's mandate—its involvement in almost every aspect of Air Force operations—allowed it to build a foundation of specialized studies over many years that formed the basis for its broader policy analysis. The latitude granted RAND in defining those studies assured its continued relevance and allowed it to adapt to a changing world, an evolving Air Force, and the emergence of other analytic institutions, some of them spin-offs from RAND itself.

These collected essays capture our pride in the past and reflect the confidence with which we face the future. Already, we are focusing on the implications of a complex and rapidly changing security environment—one characterized by profound shifts in resources, technologies, and current and potential adversaries and by new perceptions about America's military capabilities.

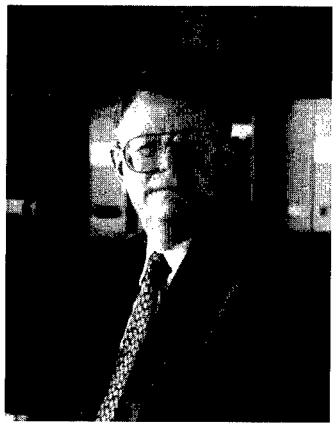
In meeting this challenge, RAND's analytical scope is expanding beyond vital traditional concerns to include new emphases on harnessing the power of information, on operations in space, on the role of uninhabited vehicles—and on innovative means of tapping private-sector energies to meet Air Force acquisition and support needs. Our most important responsibility, however, is to help the Air Force identify and plan for the security challenges

Donald H. Rumsfeld
Chairman of the Board of Trustees

Jim Thomson
President and Chief Executive Officer, RAND

of the future. This mandate takes us full circle to our origins and to the wisdom of General Arnold: "Any air force that does not keep its vision far into the future can only delude the nation into a false sense of security."

What the founders put in place with Project RAND, and what the Air Force has sustained for the past 50 years, is an institution capable of affecting the fundamental thinking of the Air Force itself—in logistics, acquisition, force employment, strategic policy, cost analysis, and many of the other subjects treated in this volume. That is the greatest legacy of the partnership of trust. We believe it will continue to bring important, sometimes entirely unforeseen, dividends in the years to come.



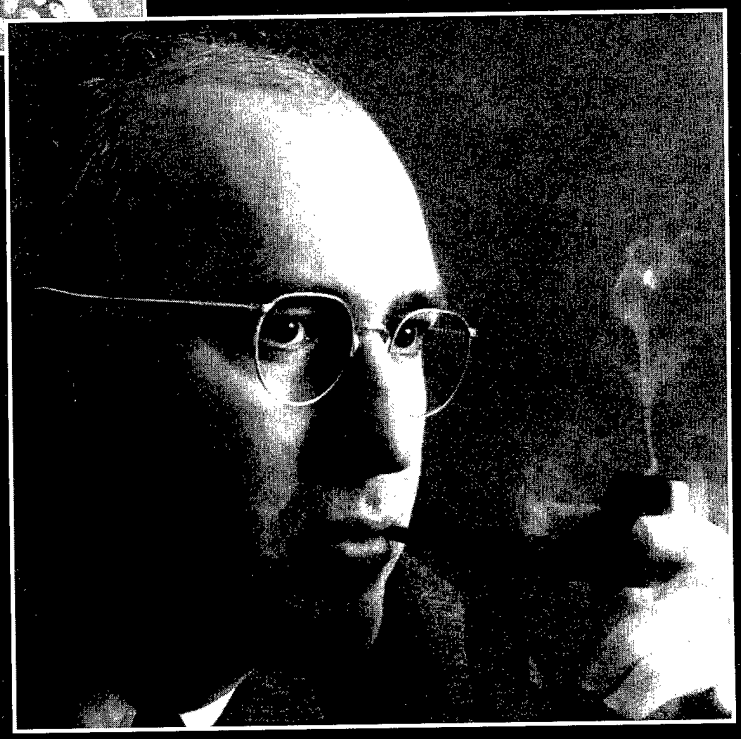
Brent Bradley
Vice President and Director,
Project AIR FORCE

Albert Wohlstetter

Fritz Sallagar

Bernard Brodie

Alain Enthoven



Ed Barlow

Franklin R. Collbohm
Director, Project RAND, 1946–48
President, The RAND Corporation, 1948–67

Bruno W. Augenstein
Director, Air Force Project RAND Programs, 1968–71

George K. Tanham
Vice President, Project RAND Division, 1971–75

William E. Hoehn
Vice President, Project RAND/Project AIR FORCE Division, 1975–80

Steven M. Drezner
Vice President, Project AIR FORCE Division, 1980–84

James A. Thomson
Vice President, Project AIR FORCE Division, 1984–89

George L. Donohue
Vice President, Project AIR FORCE Division, 1989–94

Brent D. Bradley
Vice President, Project AIR FORCE Division, 1994–present

OUT OF THE BOX

Carl Builder

Carl Builder, a defense analyst at RAND for the past 27 years, writes about RAND's long tradition of daring to think differently.

Perhaps the highest aspiration of the joint venture that initiated RAND was to explore the frontiers of knowledge. Thinking "outside the box"—or daring to think imaginatively—has been a consistent feature of RAND throughout its 50-year association with the Air Force.

As with many frontier ventures, not all of the ideas proved prophetic or helpful. Some reached too far or misjudged the unfolding future, but enough hit their mark to encourage the persistence of RAND researchers and the patience of their Air Force sponsors. Even when the ideas hit the mark, they typically challenged prevailing thinking and interests, and the clashes between their proponents and skeptics struck sparks that were sometimes fanned into flames by conflicting intellectual and institutional loyalties. On such occasions, the relationship between RAND and the Air Force was tested but never broken.

Every decade of the RAND–Air Force relationship has produced many instances of out-of-the-box thinking, but a single example from each decade is enough to illustrate the ranges of the ideas and their fates. A celebrated example came almost at once, from the mid 1940s, immediately after the creation of Project RAND: One of its first studies assessed the feasibility and utility of "a world-circling spaceship"—what we would now call a space satellite or orbiting spacecraft. Although that study garnered little attention when it was first published in 1946, more than a decade later it proved prophetic as the Soviet Union and then the United States began their race into space. In this pioneering study, Project RAND may not have shaped the future of Air Force space operations, but it clearly and accurately anticipated them by a dozen years—a respectable leap outside the box.

The 1950s saw an increasing threat of Soviet atomic attacks on Air Force strategic bombers then stationed around the world. The short range of these first-

generation jet bombers required many of them to be based forward, overseas, to be close enough to reach their planned targets in the Soviet Union. But their proximity to the Soviet Union also made them increasingly vulnerable to Soviet atomic attacks with little or no warning. Even so, the implicit assumption of Air Force planners at the time was that they would somehow gain sufficient warning of any impending attack to launch their own bombers before the Soviets could, in what amounted to a first strike. Thus, for Air Force planners, the issue of base vulnerability was of less concern than optimizing the bomber locations for a first-strike attack. In 1951, the Air Force asked for RAND's help in selecting the locations for new overseas bases for the bombers. The expected solution was an array of overseas bases and bomber assignments that optimized the effectiveness of the bomber force, implicitly for a first-strike attack.

As explained in the essay on strategy in the nuclear age, the RAND team broke with convention and suggested that the Air Force try to base the bomber force so as to survive a Soviet first-strike attack and then carry out a retaliatory second strike. This suggestion meant that bomber vulnerability should become the overriding concern, with new requirements for the protection of critical base facilities against atomic attack and for basing the bombers farther back or at home in the United States, where they would be more difficult for the Soviets to attack. But to rebase the bombers in this way, the Air Force would have to abandon or harden many of its overseas bases and rely more on its long-range bombers and aerial refueling tanker aircraft. This radical solution was unpopular with many in the Air Force, and the RAND researchers did not endear themselves to their opponents when they aggressively pressed their case. Their argument was to shake the foundations of nuclear deterrence policy—a shift from a first-strike to a second-strike posture. The study became a RAND classic, not only for reframing the question as one of greater importance, but for persistence and audacity in selling an out-of-the-box solution against strong opposition.

In the 1960s, as the threat of limited conflicts took its place alongside the nuclear threats of the Cold War, RAND began a long-lasting affection for large mobile floating bases. Such bases, comprising inexpensive, rafted steel or concrete barges, were envisioned as depots for prepositioning military materiel, aerial ports of delivery for airlifted supplies, and air bases for tactical air combat operations. They seemed especially attractive if the

In the 1970s, RAND researchers began to explore an unthinkable idea for the Air Force of that time—airplanes without pilots.

United States found itself uncertain as to both where it might have to fight next and whether it could gain the necessary basing rights in the theater of military operations. They were arguably less costly than many alternatives, including more aircraft carriers, prepositioned supplies, or sealift capabilities. But the idea was never popular enough with the military services to gain the support necessary for a thorough evaluation. It was with some satisfaction that RAND researchers who had championed this proposal learned in the 1990s that they had had an unlikely ally in another out-of-the-box thinker, Admiral William Owens, then the Vice Chairman of the Joint Chiefs of Staff.

In the 1970s, RAND researchers began to explore an unthinkable idea for the Air Force of that time—airplanes without pilots. With air defenses becoming ever more ferocious (before the era of stealth aircraft), some at RAND studied and touted the potential of unmanned air vehicles (UAVs) for many combat air operations. Of course, this was not a welcome idea to the pilots in the mainstream of the Air Force. To sweeten the bitterness of the idea, the RAND advocates called their proposed pilotless aircraft RPVs—*remotely* piloted vehicles: The RPVs would still need pilots, but the pilots would "fly" or control their aircraft from the ground. This concession hardly made the proposal more attractive to pilots, but they need not have worried—the idea was still at least 20 years ahead of its time. The idea persists today as an issue and seems to have made some headway, but the day of the UAV or RPV, as then imagined, is yet to come.

In the 1980s, in several different initiatives, RAND

A high-performance unmanned surveillance aircraft (Predator Tier III), now in flight testing.

researchers suggested that precision-guided munitions—launched from aircraft, ballistic missiles, and even from space—could supplant nuclear weapons for many strategic targets and campaigns. These suggestions were greeted with skepticism by many, but especially from within the Strategic Air Command (SAC)—then devoted to the long-range delivery of nuclear weapons. The RAND proponents and their few Air Force allies were repeatedly rebuffed, but a decade later, they saw their vision realized in the air campaign waged against Iraq in Operation Desert Storm. Recently, a former commander-in-chief of SAC confided that he had been wrong in his rejection of the then-radical idea that nuclear weapons could be largely displaced in strategic air campaigns by smart conventional weapons. The shot had been accurately called by several at RAND, and some in the Air Force had heard and acted.

It would be wrong to conclude that the Air Force was the only leash on out-of-the-box thinking from Project RAND and Project AIR FORCE. Impediments or restraints have always existed within RAND itself. The enormous range of research at RAND always attracted creative thinkers and the best of specialists in their disciplines. But radical ideas can challenge the value of the existing knowledge of specialists—their stock in trade—as well as the way institutions see themselves. RAND researchers with new ideas often found themselves first under attack from their specialist colleagues. And although RAND management clearly took pride in RAND's reputation for innovation, the prospect of

challenging RAND's clients could raise some justified concerns.

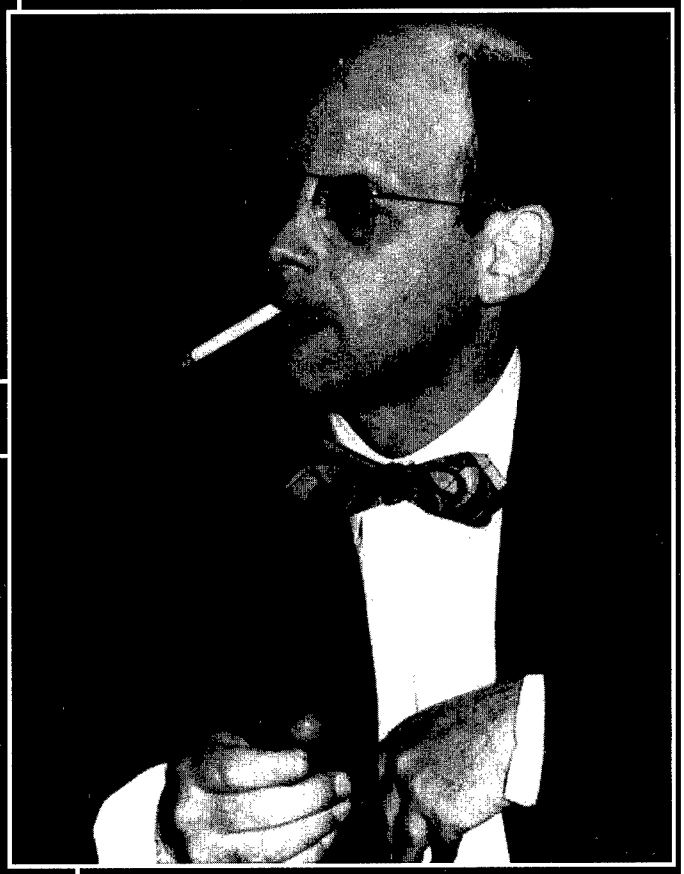
So innovators often had to run a gauntlet between skeptical, even threatened, colleagues and a nervous management before they could enjoy the honor of wrestling with the Air Force over a radical idea. That path was daunting and took courage, and RAND's reputation for innovation is probably a testimony more to those who had the fortitude to fight for their ideas than to the RAND research environment or even to the ideas themselves.

Now, in the middle of the 1990s, that path is still attracting innovative and resilient individuals who are challenging current notions about the application of air and space power. For example, even as the Air Force validated many of its concepts for conventional war in Operation Desert Storm, some RAND researchers have sounded a warning that the future applications of airpower may be found more in constabulary operations—peacekeeping and humanitarian missions—than in warfare. Whether they are right or wrong may not be determined for another ten years, but such independent—even contrary—thinking is still clearly alive and healthy as an integral part of Project AIR FORCE.

Ed Quade

David Novick

Ed Paxson



Ernie Plesset

Jimmy Lipp

SPACE

Bruno Augenstein

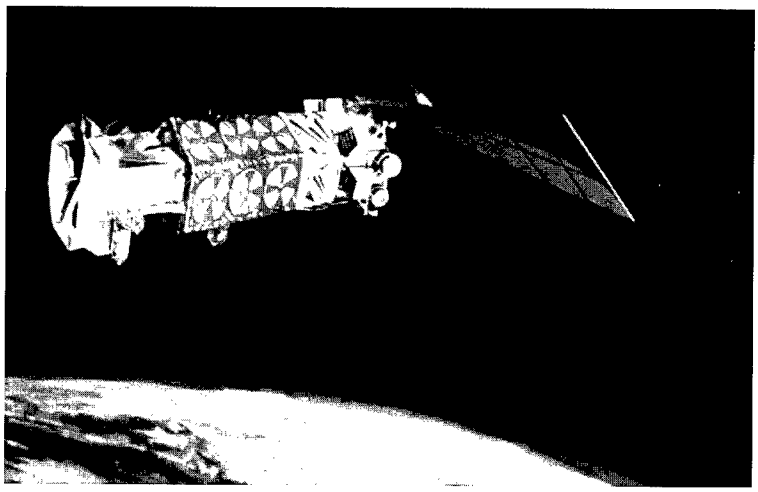
Bruno Augenstein, a physical scientist with RAND for 46 years, was a central figure in the development of U.S. space and missile programs. He writes about the confluence of forces that brought RAND to the forefront of military space technology for many years.

For those of us who participated in RAND's space-related work in the initial years, say from 1946 to the early 1960s, the period was a golden age. It sprang from an unprecedented level of interaction between the Air Force, RAND, and industry that made it possible for ideas to be implemented quickly on the heels of conception. There was a palpable sense of urgency and purpose: We were bent on harnessing the capabilities of wartime rocket technologies to ensure that the United States acquired strategic information and maintained strategic power in that confrontational era.

Two of our earliest studies—one on earth-circling satellites and the other on a comparison of ramjets and rockets as strategic weapons—set the stage for two strains of work, distinct but intersecting, that dominated RAND's space research for the next 20 years: satellite reconnaissance and ballistic missiles. The early studies moved RAND to the forefront of the most advanced fields of military technology. And when their time came in the 1950s, RAND's satellite and missile studies provided the Air Force credible blueprints for those two new fields.

Early Satellite Work

RAND's first report, *A Preliminary Design of an Experimental World-Circling Spaceship*, was published in 1946 when RAND was still part of Douglas Aircraft Company. Major General Curtis LeMay of the (then) Army Air Force was eager to make space operations an extension of air operations. He asked Project RAND to write a feasibility study of space satellites within three weeks, knowing that the Navy had commissioned two industrial contractors to report on satellites. (The report came in two days before the Navy document.) A more comprehensive study the following year was an authoritative analysis of the potential of satellites for reconnaissance missions.



The DMSP (Defense Meteorological Satellite Program), an early classified outgrowth of the Kellogg-Greenfield weather satellite proposals.

In 1948, the Air Force was assigned custody for the U.S. satellite program, and the Air Force designated RAND to manage and integrate the program. In the years that followed, RAND formed alliances with subcontractors in analysis of flight mechanics, propulsion, satellite technologies, and new materials (e.g., titanium) for very-high-speed atmospheric flight, and many other issues. Recent declassification of the CORONA and FEEDBACK systems now allows RAND to discuss one major achievement of these alliances: RAND asked the Ampex Corporation, a subcontractor, to develop data storage on magnetic tape, work that helped stimulate the commercial videorecorder industry, substantially expanding work at a primitive stage of development.

RAND was the first to recommend that satellites be used for weather observation. The analysis suggested methods for photographing the earth from space—the beginning of a substantial body of work on that subject in the 1950s—and recommended an approach that was later used in the Tiros weather satellite developed by

ARPA and NASA. The key RAND researchers, William Kellogg and Stanley Greenfield, were honored a decade later by the American Meteorological Society for their seminal work.

RAND was also deeply involved with reconnaissance using balloons, which many at the time favored as a more immediate possibility than either aircraft or satellite systems. While balloon programs evolved into operational systems that collected information on the USSR, their main contributions surfaced in the later CORONA satellite program: The balloon systems served as test beds for cameras, midair snatch recovery of payloads, and reliance on direct film return for high-resolution reconnaissance.

Our work on satellites culminated in 1954 with the publication of the FEEDBACK study, the first comprehensive overview of the military applications of space-based systems. The FEEDBACK report was edited by James Lipp and Robert Salter, and was supported by nearly 200 other named researchers contributing essential thought and effort. This landmark study proposed a satellite program using electromagnetic transmission of data to earth—a technique now commonplace—and discussed a host of other systems, technical options, and operational issues. In effect, the FEEDBACK study served as "the basis for the first military satellite program," as it is memorialized by John Logsdon in *Exploring the Unknown* (from the NASA History Series, 1995).

Missiles

The parallel stream of RAND work on intercontinental ballistic missiles (ICBMs) was greatly accelerated in 1952 and 1953, while RAND worked on the feasibility of an ICBM program at the same time as the TEAPOT Committee, a DoD committee chaired by John von Neumann that reviewed missile programs for the Secretary of Defense. RAND briefed its findings to various audiences, including the TEAPOT Committee, in 1953 and produced a report in February 1954 that has been called "the single most crucial document of the missile age" (according to D. MacKenzie in *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance*). The report offered a synthesis of insights on high-yield weapons, precision guidance, reentry techniques, rocket technologies, and strategic reconnaissance and outlined a program that would provide the United States with a new level of strategic power. This report was written by Bruno Augenstein and fundamental sup-

porting research was undertaken by Carl Gazley, William Frye, and others. Shortly afterward, the TEAPOT group presented its own recommendations, which mirrored those of RAND. These two reports prompted the Air Force to launch its ballistic missile program in 1955. The Thor, Atlas, and Titan space-launch vehicles developed for that program underpin the U.S. space-launch capability, along with the Space Shuttle, to this day.

RAND's missile work had many direct and indirect influences on the satellite work that matured over the same period. The development schedule, cost, and manning recommendations for the FEEDBACK satellite program, for example, were outgrowths of the ICBM analyses. The reentry techniques for reconnaissance satellites RAND proposed in the post-Sputnik period also had their roots in RAND's missile research.

RAND's achievements in ICBM technology had one unexpected consequence. Several senior government officials, top-level Air Force officers, and some members of TEAPOT itself approached Frank Collbohm, then RAND's president, to sound him out on the notion of RAND assuming a "system engineering role" for the ICBM. Frank quickly would have none of it, saying that it would change RAND unacceptably (a decision some of us felt was overstated). As it turned out, Ramo-Woolridge Corporation, subsequently renamed the Space Technology Laboratories, assumed that system engineering role, after RAND turned it down.

The CORONA Era

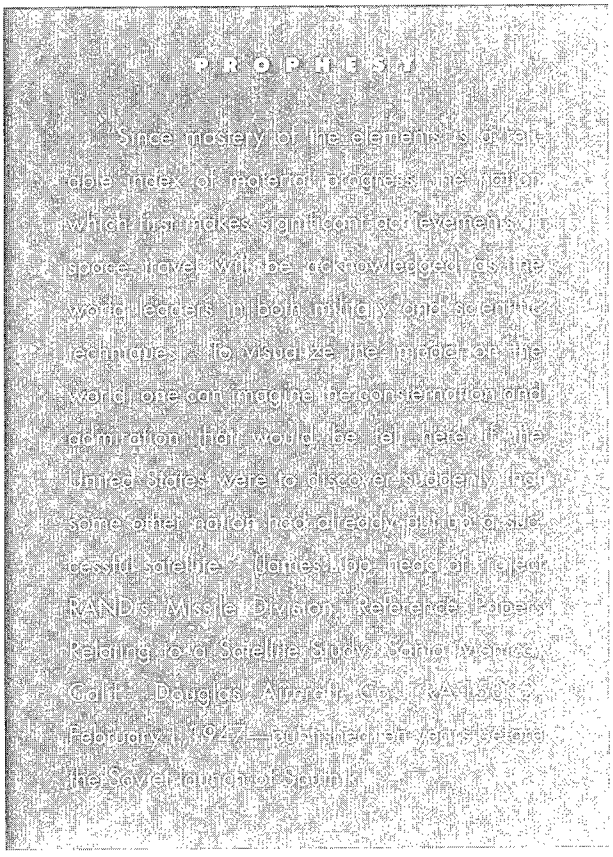
A final round of RAND's observation satellite activities occurred after 1956. Influential researchers included Robert Buchheim, Amron Katz, Cullen Crain, Merton Davies, Ted Garber, Lou Rowell, Richard Raymond, and others. Spurred by prior research, RAND proposed a family of recoverable reconnaissance satellites. These recommendations were well-timed in the post-Sputnik era, when there was intense interest in accelerating and modifying the existing programs at Lockheed, which were based on earlier satellite concepts from RAND's FEEDBACK study. For a brief period in November 1957, one of RAND's concepts was considered for the payload stage of CORONA—a spin-stabilized payload stage, shaped like a football, together with a panoramic camera that would scan as the payload rotated—but the final design called for an attitude-stable system instead. Development work on CORONA began in earnest in

early 1958. The CORONA system that Lockheed fielded, using camera types and direct data-recovery modes earlier tested in balloon reconnaissance programs, provided a decisive tool for maintaining the strategic balance in the Cold War. During the "CORONA era," from 1961 into the early 1970s, the satellite gathered invaluable data on the Soviet Union.

Soon after the launching of Sputnik 1, RAND was considered the institution most qualified to educate government leaders on what it all meant. RAND offered a course to 400 Air Force and DoD officials that later formed the basis of RAND's *Space Handbook*, an authoritative report requested by Congress that made the Government Printing Office's list of the ten best-sellers of all time and later became a commercial book.

Shift in RAND's Role

At one time, hundreds of RAND staff and subcontractors—all of whose names deserve to be recorded here—were engaged in space work. A proper recounting of history would show how all these individuals contributed essential support in space-related work, some up to the current day, like Richard Frick. Eventually, many of the staff migrated to key industry and government positions, where they helped develop programs that had originated at RAND. Others went on to help establish the Aerospace Corporation in 1960, an FFRDC set up to meet the growing demand for detailed technical analysis of space systems. At about this time, RAND began to



reduce the range of its space research but maintained the tradition of analyzing broad policy issues, including assessments of the utility, technical feasibility, and cost of specific space programs.

An important example of this work is the study of U.S. communication satellites that directly influenced the structure of U.S. communication satellite programs in DoD, NASA, and the COMSAT Corporation in the 1960s. Research on the Space Shuttle in the 1970s and 1980s offered evidence that NASA's estimates of its capability and cost were drastically in error and cautioned the Air Force about over-reliance on the shuttle as a launch vehicle. In the late 1980s, a study on the Air Force National Aerospace Plane (NASP) raised doubts about the cost and technological maturity assumed for the NASP program.

Our current work is largely devoted to studies of the utility and affordability of alternative space systems for military operations. We are assessing current space program plans and new concepts and space technologies in an operational context: How many special characteristics do new systems need to meet future demands, and will the DoD be able to rely more heavily on commercial space systems in future conflicts? What is the role of reusable launch vehicles, including proposed transatmospheric vehicles or space planes, for rapidly deploying sensors to increase battlefield awareness and for executing other missions? Our work also explores better ways to integrate systems and protect them in wartime: How can the flood of information from sensor systems be processed and integrated to provide a coherent picture of the battlespace and be transmitted to operators when they need it? How can commercial systems be integrated with military systems? How can the use of commercial systems, including the Global Positioning System satellites, by adversaries best be reduced in wartime?

Space research flourished at RAND because of the healthy interchange of ideas within RAND and between RAND and the national community, an interchange that continues to allow us to serve as an "honest broker" for the Air Force and industry. All those who fostered the culture of innovation and imaginative space research maintained at RAND deserve great credit. Today's world could have been very different without that environment.

STRATEGY FOR THE NUCLEAR ERA

James Digby

Jim Digby is a consultant who served as an analyst and manager at RAND for 40 years. He writes about the development of air strategy and discusses RAND's ideas about the posture of strategic forces.

Project RAND came into being just as the nuclear era was ushered in, and strategy for that era was our first, most compelling concern. Nuclear strategy presented challenges about which history could teach us only a limited amount, and even that had to be innovatively adapted and expanded as we went along.

Fortunately, the staff of Project RAND was young, bright, inventive, and highly motivated. Generally tops in their college classes, many had already served their country in various ways: Ed Paxson had made training films; Charles Hitch had been an Oxford don before he became a corporal planning how to destroy the Nazi economy; Larry Henderson had been a science advisor to Air Corps generals; and I had been an Air Corps lieutenant serving as squadron radar officer. But most of us knew little about formal air strategy. So Paxson had the library order the works of Sun Tzu, and Olaf Helmer organized games of *Kriegspiel*, the strategy-heavy blind-chess game of the old German General Staff.

While Hitch led studies of the economic effects of bombing and RAND's Social Science Department analyzed Soviet behavior and the effects of war on morale, Paxson organized RAND's first major analysis of an air campaign against the Soviet Union. He drew on his colleagues' work in targeting, morale, aircraft design, and future weapon characteristics. He called this a *systems analysis* to distinguish this broader kind of study from wartime operations analysis. (See the essay on analytic methods.)

In 1949, the blunt Soviet belligerence of the Stalin era and a rapidly growing U.S. bomber force led RAND to organize its next major systems analysis: the defense of the United States against air attack. Ed Barlow, who had designed an advanced radar at Sperry, led a study of air defense even broader and more multidisciplinary than Paxson's.

Nuclear strategy presented challenges about which history could teach us only a limited amount, and even that had to be innovatively adapted and expanded as we went along.

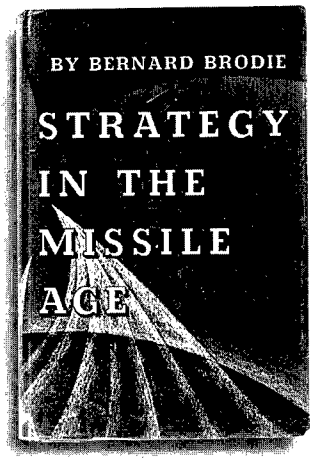
Barlow devised a flow chart for his analysis and appointed experts to analyze each box. There were subprojects for the Soviet threat, target selection, fighter design, airborne radar, ground radar, ground observers, weapons, antiaircraft guns, bombing tactics, and over a dozen other specialties. Perhaps more important than these elements, the study looked at what the consequences would be under various circumstances and for a spread of assumptions. The project teams also invented and designed several needed weapon systems that prefigured systems the services would subsequently develop and deploy—for example, the Army's Hawk air defense system, a method of tying radars together; some ways of rejecting ground clutter in airborne radar; and, later, the Genie nuclear air defense rocket.

Several members of the team labored mightily to put all of this together in a systematic way and to produce recommendations for fighter, radar network, and antiair missile design and many other factors. Project RAND's Director, Frank Collbohm, and his deputy, Larry Henderson, arranged for a series of high-level briefings to Air Force officials.

As this work progressed, RAND brought in a political scientist trained at the University of Chicago who was planning to write a book on nuclear strategy. That work, *Strategy in the Missile Age*, was the first of its kind. It was read by everyone concerned with national security strategy, and it highlighted the issues that would be debated for the next several decades.

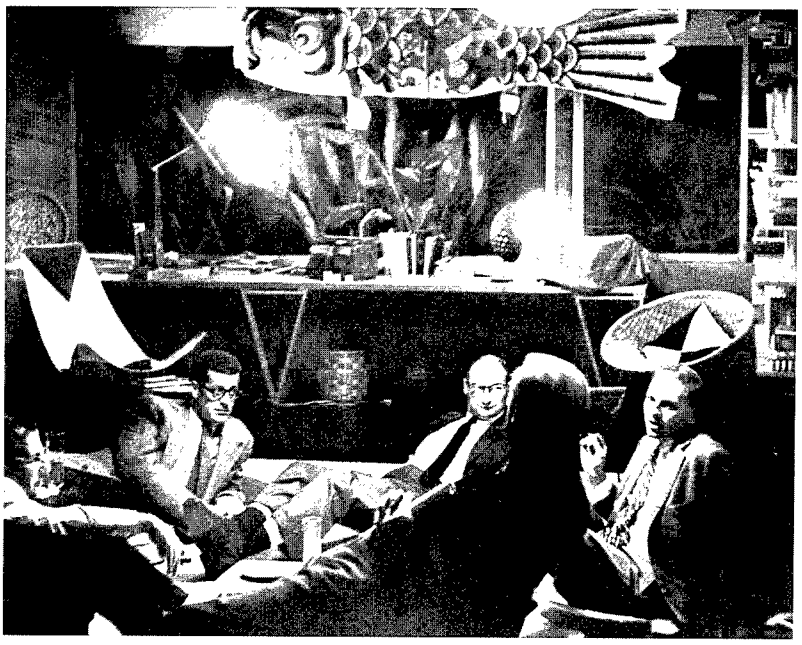
A major factor in RAND's contemplation of strate-

gies was a remarkable series of studies that Albert Wohlstetter led on designing and protecting U.S. strategic forces. This work showed how fragile the U.S. ability to deter Soviet attack would be if the only chance of survival was to make the first strike. Wohlstetter and his team accumulated detailed knowledge through visits to Strategic Air Command bases, engaged experts to design bomber protection, and made many thoughtful observations about air operations. Their findings challenged the current strategy, which was focused entirely on first-strike capability. Wohlstetter's team demonstrated that the Air Force could not be assured of deploying its strategic forces in the event of a surprise nuclear attack. Instead, it should protect those forces—by hardening structures—so that a second strike could be launched. Although the Air Force resisted the recommendations at the time, it heeded them later when the Atlas missile was developed in 1960 and Harry Rowen made the case for changing its above-ground launcher to a well-protected underground silo.



The success of Wohlstetter's studies and the expertise gained in supporting them helped RAND perform and promote a number of other strategic studies, notably Herman Kahn's civil defense study. Several leading RAND figures contributed significantly to three key studies in the late 1950s: the NSC-sponsored Gaither committee, the Geneva Surprise Attack Conference (attended by the United States, the Soviet Union, and others), and the Air Force's Strategic Offensive Forces Study. The last was led by Barlow and made a number of recommendations for future airpower to General Tommy White. In 1959 and 1960, Bill Kaufmann expanded his portion of this study into a forceful briefing on counterforce, which helped make him an influential member of Secretary Robert McNamara's Department of Defense in the 1960s.

By the time McNamara became Secretary of Defense, much of Project RAND's 1950s work had been published in books and articles: Brodie's *Strategy in the Missile Age*, Wohlstetter's *Delicate Balance of Terror*, and Kahn's *On Thermonuclear War*. In some ways, the most influential was *The Economics of Defense in the Nuclear Age*, by Charles Hitch and Roland McKean, which McNamara read closely just before he took office. That



After-hours meeting in the home of Albert Wohlstetter (foreground). Harry Rowen and Andrew Marshall are second and third from left. Their subject: economic recovery of the U.S. after an all-out war.

reading led him to tap Hitch, Rowen, and Alain Enthoven for the Department of Defense, along with other RAND analysts appointed later.

The influence of these RANDites was pervasive, extending not only to strategic force questions but to the way DoD analyzed service proposals. The latter sometimes strained RAND's relations with the Air Force. Nevertheless, many subsequent RAND studies were well-received by the Air Force, such as RAND's suggestions for using computers to plan and control attacks, and for increasing the accuracy of missile systems, particularly the use of jam-resistant radio-assisted inertial guidance.

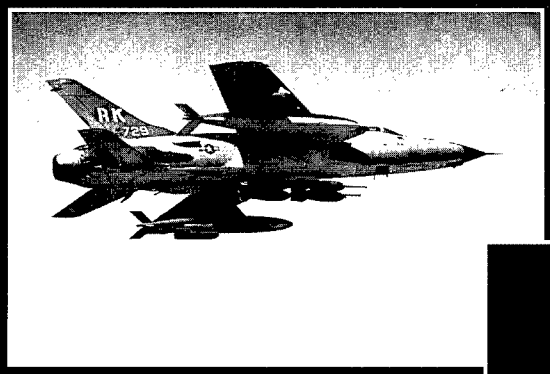
From the beginning, RAND research recognized the political constraints on nuclear attacks and, accordingly, paid close attention to the strategic potential and limita-

tions of nonnuclear air strikes. In the early 1970s, Phil Dadant and Colonel Jim Sibley (on loan from the Air Force) analyzed improvement of nonnuclear attacks on air bases. That work, in turn, led to studies in the 1980s, including a conference organized by Carl Builder, which produced papers on precise long-range nonnuclear delivery systems.

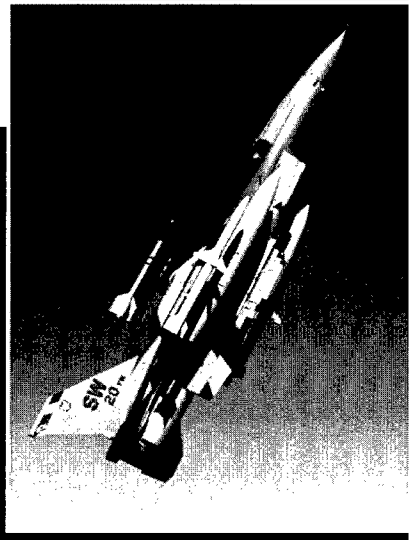
In the late 1980s, Russ Shaver revisited questions of active defenses and various basing options for the Peacekeeper ballistic missile. He later led analyses of basing options for a "small ICBM," work that had major implications for policies on arms control. In a similar vein, Jim Thomson (newly arrived from the National Security Council) directed a broad-gauge study about how a successful defense against ballistic missiles would affect strategic stability, our relations with allies, and arms control.

In thinking about the history I have been recalling, I believe it has an important lesson for future research on nuclear and other Air Force strategy, as well as national security analysis in general: A major reason for the influence of RAND's recommendations—and the credibility they had—is the many detailed, technical, and innovative studies that backed up the work. For example, researchers looked into the details of engine upgrades, radio propagation, structural design, orbital mechanics, base hardening, and many other technical issues, knowing that the devil is the details for even—or perhaps especially—conceptual breakthroughs.

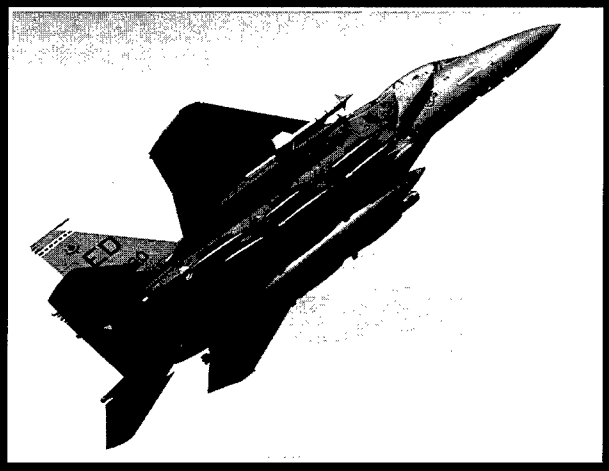
B-29s based in Okinawa, 1952



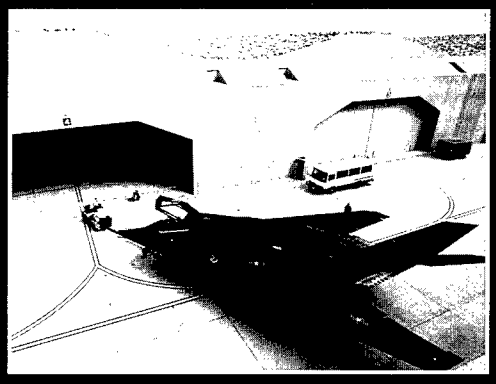
F-105 in Southeast Asia, 1969



F-16C with HARM targeting system

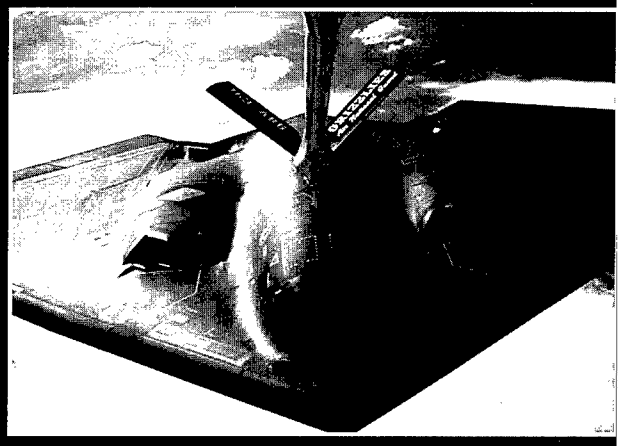


F-15E Strike Eagle



F-117 in Desert Storm, 1991

Prototype for the F-22, scheduled to enter the inventory in the 2000s



B-2 bomber being refueled by KC-135, 1994

THEATER AIR OPERATIONS

Jack Ellis

Jack Ellis, who began his RAND career as an aerodynamicist when Project RAND was still part of Douglas Aircraft Company, writes about how RAND research helped decrease the vulnerability of theater forces, particularly in Europe, and identified the primary role of tactical airpower in various scenarios.

Into the early 1950s, PAF research focused primarily on applying the rapidly developing aircraft and missile technologies to intercontinental bombardment systems supporting the Strategic Air Command mission. In the years that followed, events and shifting strategic and political conditions widened that focus to include extensive work on tactical air and theater air forces.

NATO/USAFE Vulnerability

In the early 1950s, in response to the ever-growing Soviet air and ground forces stationed in eastern Europe, RAND began periodic assessments of how USAFE and NATO theater forces could cope with that threat. These studies ran the gamut from consideration of the early manned-bomber threat to the more recent development of theater ballistic missiles (TBMs). In 1953, RAND's first comprehensive NATO-defense study specified the elements of vulnerability associated with USAFE's deployed forces and developed a coherent set of remedial actions. This project was led by Igor Ansoff, with major contributions from Roger Snow, Dave Davis, Jack Ellis, and Tom Holdiman, the first USAF officer to serve a formal tour at RAND. The findings supported development of what later became the official NATO Dispersal Plan.

PAF research on NATO's vulnerability and military strategy identified alternative approaches for the defense of Europe. Results of one study called into question the effectiveness of the then-existing "tripwire" strategy. This made the study team unpopular in high places. Consequently, the team was "stranded" in Paris with nothing to do for a week—until the Supreme Allied Commander, Europe reluctantly allowed them to present the results in the theater.

In the mid-1980s, PAF's extensive experience in NATO and tactical air operations in general culminated

in a major study led by Steve Drezner and Charles Kelley. The Air Force had urgently requested a comprehensive analysis of the threat to NATO tactical air forces from a Soviet TBM attack. The RAND team took a systems-level view of the problem by conducting a theater-level campaign analysis that included joint actions of all the services, the play of coalition forces, and the effects of changes in logistics support and scenario assumptions. This approach, which has now become standard practice in the modeling community, was unusual at the time. Besides identifying the defensive measures that could be taken to guard against TBM attacks, the study results challenged current doctrine on the uses of airpower by suggesting that, after establishing air superiority, the primary role of tactical air should be to support ground forces rather than to conduct an air war.

The theater-level analysis was made possible through TAC SAGE, a model Dick Hillestad developed in the mid-1980s, drawing on algorithms initially created in the Air Force. The new model allowed the analyst to introduce a military objective—such as stopping ground forces—from either the blue or the red perspective and find out from the model how best to accomplish it. Such a tool encouraged fruitful debate among NATO commanders with different assumptions about how to allocate airpower against the Soviets. This model later provided the underpinning for RAND's extensive Allied Air Forces Central Europe air campaign analysis.

Third World Conflict and Limited Nuclear War

After the Communists consolidated their control over mainland China and the Korean War ended, concerns arose about the potential Chinese threat to other Asian countries. PAF's Project Sierra initiated a large-scale investigation of hypothetical wars in Thailand, Burma, Formosa, Korea, and Indochina. The project was led by Ed Paxson and involved, among others, Lt Col Bill Jones (a USAF officer assigned to RAND), Ed Quade, Milt Weiner, and several retired Army, Air Force, and Marine Corps officers. The results caused policymakers to recognize the possibility of a Communist threat beyond Europe and Korea. War gaming, largely manual, was a key methodology in this work, which was the spiritual forerunner of RAND's computerized Strategy Assessment System, used by many throughout the Air Force and elsewhere in the Department of Defense.

Also, in the late 1950s, RAND began a pioneering examination of limited nuclear war and its implications

KC-10 Boom operator refueling an F-4

for Air Force planning. This research was led by Fritz Sallagar, supported by Harvey DeWeerd, Jack Ellis, Alex George, Leon Gouré, and Terry Greene. The team developed a hypothetical political-military scenario, set in Iran, that provided a plausible context and rationale for limited nuclear conflict. The results ran counter to conventional wisdom at the time, which focused solely on intercontinental strategic warfare, and the Air Staff delayed their release. Eventually, however, the reports were distributed, and they contributed to a shift in strategic thinking: Limited nuclear warfare was gradually recognized as a possibility that had to be planned for.

Combat Analyses

Throughout the conflict in Vietnam, RAND conducted research to improve the effectiveness of airpower. One

significant effort (in 1965 and 1966) supported Air Force combat testing of the F-5A (nicknamed the "Skoshi Tiger") as a counterinsurgency aircraft. The RAND team (Greg Carter, Jack Ellis, Art Peterson, and Marv Schaffer) helped write the test plan, spent six months in Vietnam collecting and analyzing the combat performance and effectiveness data, and wrote the major part of the final report that the USAF Tactical Air Warfare Center published. These results confirmed the utility of the simple, light, jet-fighter concept in the context of the Vietnam conflict. The surviving F-5A aircraft were turned over to the Vietnamese air force and remained in service there until the war ended.

Operational Requirements

In the spring of 1981, the Air Force asked RAND for a wide-ranging review of the factors that would affect decisions about the preferred characteristics and performance of the next-generation tactical fighter. Led by Natalie Crawford, this study synthesized a large body of work that responded to the immediate needs of senior Air Force managers by providing the basis for identifying the need for tactical air and for specifying the quantitative and qualitative performance characteristics for future aircraft. The results also provided an independent view of the relative priorities of air-to-air and air-to-ground capabilities and outlined new strategies for acquiring and supporting advanced aircraft systems.

One of PAF's major contributions has been the development of a systems approach to the analysis of tactical air operations that, over the years, has been adopted by the Air Force planning and operational communities. The heart of the Air Force is its theater air operations, and PAF remains engaged in analysis of how those forces should be modernized and employed. The work we are doing today relies heavily on the research of those who came before us.

COMPUTING

Willis Ware

Willis Ware, a computer expert with RAND for 44 years, writes about how RAND research has contributed to the information revolution of our time.

Project RAND has a historic record of achievement in the development of computing: RAND staff designed and built one of the earliest computers, developed an early on-line interactive terminal-based computer system, and invented the telecommunications technique that has become the basis for modern computer networks.

Project RAND was also the first to exploit new mathematical and computational techniques to solve Air Force problems and was a force behind the introduction of computing to the Air Force at all levels. RAND staff members served as advisors throughout the 1950s and 1960s, as the Air Force absorbed computer technology into its structure. They helped establish the career path for computer specialists, participated in the Scientific Advisory Board, designed the curriculum and taught courses for the DoD Computer Institute, and participated in formal study groups and committees sponsored by the Air Staff. In all these interactions, Project RAND helped the Air Force make the transition to computer maturity and supplied it with computer-based analytic methodology and software.

In the Beginning

From its inception, RAND research was heavily quantitative, and calculating aids were in great demand. Project RAND acquired a Reeves Electronic Analog Computer in 1948 for missile and orbital simulations and promptly made a number of engineering improvements that were adopted by the industry of the time. Calculations for early studies were done on punched-card "electric accounting machines." Early models did only simple arithmetic, generally only a few operations per card; later models could be "programmed" by making electrical connections among the parts through wiring on removable plugboards. RAND pressured IBM for many years

to produce improved equipment, which eventually could do many tens of operations per card. Innovative RAND programmers created large and complex plugboards in a continuing effort to create more elaborate computational environments.

Demand for random numbers in support of modeling studies prompted construction of a special electronic mechanism to generate them. This work became the well-known *A Million Random Digits with 100,000 Normal Deviates*, published in 1955, whose tables have become a standard reference in engineering and econometrics textbooks even to this day.

Efficient calculation of mathematical functions was a trying problem. Cecil Hastings' *Numerical Approximations for Digital Computers* was a major contribution in this area. It has been estimated that this research saved enough machine time and memory (measured in dollar value) to have financed Project RAND for 15 years.

The Move to Electronic Digital Machines

The demand for solutions to complex analytic studies outstripped the computing power of the time. In 1949, a RAND team (John Williams, Bill Gunning, and George Brown) visited major potential vendors of electronic computers to assess future possibilities for electronic computers. One of them described the state of the art as "dismal"; another wrote in the trip report that "they were all doing tweaky things."

So RAND decided to build its own computer. It was one of five organizations in the country that decided to piggy-back on the work of John von Neumann, whose project at the Institute for Advanced Study, Princeton, N.J., was building the first parallel scientific computer. With Air Force funding, a team of RAND engineers (led by Gunning) started building the machine in the basement of the building at 4th and Broadway in Santa Monica. The new computer, named JOHNNIAC after von Neumann, first became operational in early 1953 and stimulated a necessary surge of system software development to make the machine efficient and convenient for users.

Computer Science R&D

With the JOHNNIAC, every detail of data flow, every step in program logic, managing memory allocation, and handling input-output actions had to be conceived and programmed for each problem. Memory was always in short supply; machines were never fast enough; magnet-

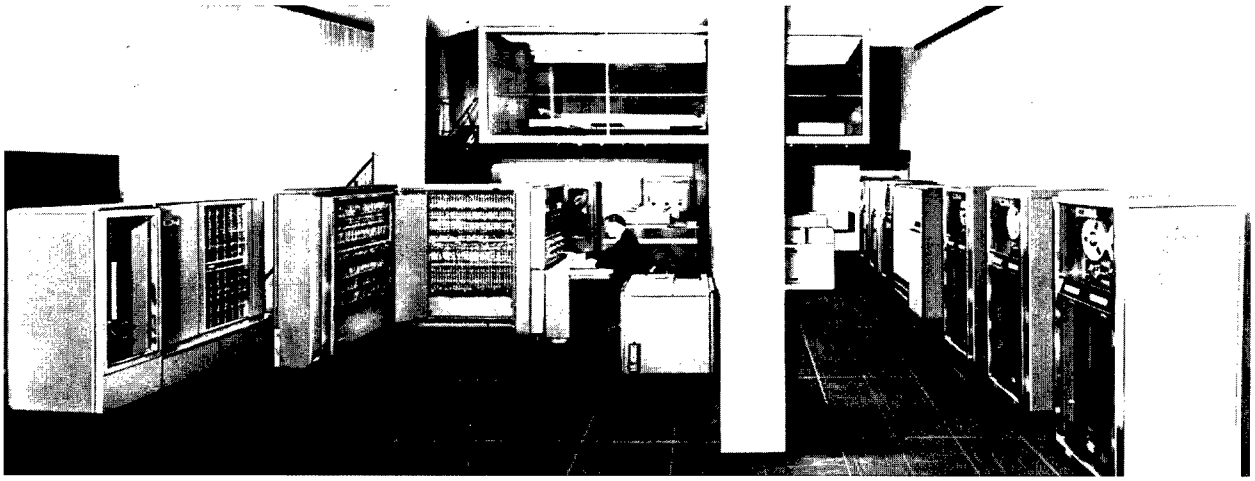
ic drums were always too small. Such problems led to innovative software development and tricks, as well as ingenious mathematical algorithms.

At the same time, a commercial industry was beginning to emerge. In late 1953, RAND installed an IBM 701 (serial number 11). It came with rudimentary programming support tools, such as an assembler and a library. However, since the concept of an operating system had not yet evolved, the programmer would have hands-on possession of the machine for a specified period of time. At the end of the assigned time slot, a printout (memory dump) and perhaps a card deck would be the basis for examination of the program's behavior. If the run crashed, a special camera arrangement could take a Polaroid picture of the display lights on the console.

The evolving demands of analytic studies and the potential of new computer technology led to a variety of innovative applications in software and mathematical algorithms. Among the most important RAND contributions were linear programming for optimization problems (George Dantzig) and the associated Simplex method of computation, dynamic programming (Dick Bellman) and its software; later, the so-called Information Processing Languages (developed by Al

Keith Uncapher at JOHNNIAC console

Chuck Baker and JOSS



A single IBM 704 in 1954

Newell, Cliff Shaw, and Herb Simon), which became the basis for subsequent artificial intelligence and expert-system software; and SIMSCRIPT, a language for simulation and modeling developed by Harry Markowitz, who left RAND to form his own software company. Two of RAND's analysts in this area—Herb Simon and Harry Markowitz—went on to become Nobel Laureates.

Commercial machines were evolving so rapidly that it was economically unrealistic to upgrade the JOHNNIAC. However, that machine continued to be the basis of engineering advances, such as the first commercially produced magnetic-core memory; the first 140-column–wide, high-speed impact printer; and a swapping drum to support multiple users. The JOHNNIAC also supported the development phase of the Tablet, the first operational digitizing surface by which freehand movements of a pen could be digitally entered into a computer.

Milestones for the Information Revolution

Of particular importance was the JOHNNIAC Open Shop System (JOSS). Developed by Cliff Shaw, JOSS-1 was a very early on-line, time-shared computer system for individual users. It led the state of the art by allow-

RAND AND THE ORIGINS OF THE INTERNET

In 1962, the year of the Cuban missile crisis, a nuclear confrontation seemed imminent. In the aftermath of a nuclear attack, how would U.S. authorities communicate? How could any sort of command and control network survive? RAND researcher Paul Baran developed a solution that has evolved into one of the major technological innovations of our time.

Paul Baran

Simulation suggested that neither the long-distance telephone plant nor the basic military command and control network would survive a nuclear attack. Although most of the links would be undamaged, the centralized switching facilities would be destroyed by enemy weapons. Consequently, Baran conceived a system that had no centralized switches and could operate even if many of its links and switching nodes had been destroyed.

All of the nodes in this unusual network would have equal status; be autonomous; and be capable of receiving, routing, and transmitting information. Under Baran's concept of distributed communications—now called packet switching—each message would be broken into a series of short, fixed-length pieces, and each would be sent as an individually addressed packet that would find its own way through the network by whatever route happened to become available, jumping from node to node until it reached the final destination. If parts of the network were destroyed, the self-sufficiency of each node plus the data within the packet allowed the node to seek alternative ways of moving the packet along.

In 1969, this decentralized and virtually invulnerable concept was given its first large-scale test, with the first node installed at UCLA and the seventh node at RAND. Funded by the Advanced Research Projects Agency and called ARPANET, it was intended for scientists and researchers who wanted to share one another's computers remotely. Within two years, however, the network's users had turned it into something unforeseen: a high-speed, electronic post office for exchanging everything from the most technical to the most personal information.

In 1983, the rapidly expanding network broke off from its military part, which became MILNET. The remainder became the Internet, and the name ARPANET was retired in 1989. Having outlived its doomsday origins and become a facility for everyday use by millions of people around the globe, the Internet is currently morphing into the World Wide Web to become an all-encompassing, affordable, universal multimedia communications network for the future.

ing tens of users to work at the same time on one machine. By the mid-1960s, several Air Force installations had terminals linked via telephone connections to the JOSS-2 in Santa Monica.

The single Project RAND study with the most lasting and widest technological impact was Paul Baran's work on the concept of "distributed communications"—now known as packet switching. Developed in the mid-1960s in response to an Air Force requirement for communications able to survive a nuclear attack, this work defined the concept underlying modern data networks—from international to local-area networks. In particular, packet switching is the communication protocol for the Internet and the Ethernet.

By the time JOHNNIAC was finally retired in 1966, a large commercial industry had evolved with extensive software for every machine, and RAND shifted entirely to commercial sources. UNIX systems became the choice for computer science research, and the concept of electronic messaging evolved. RAND computer scientists perceived the requirement for a comprehensive mail system and, over a weekend in 1979, demonstrated the principles of what became the RAND-MH message-handling system. This system became the model for other commercial mail systems and is a part of current UNIX software distributions.

Integration and Security Issues

Also in the 1970s, PAF conducted a major computer-resource management study to advise the Air Force on charting its long-term course for the acquisition, management, and operation of its computers, software, information systems, and related personnel. Staff members advised on then-innovative digital avionics and supported Air Force managers on acquisition of modern computer-intensive aircraft. In the 1980s, PAF continued its computer-science work with the development of programming languages tailored especially to battlefield and other military simulations, and incorporating both rule-based and object-oriented constructs—such languages as SWIRL, TWIRL, and ROSS.

By the 1990s, computer science under PAF sponsorship had given way to direct involvement with Air Force–specific issues, such as the security of information systems, the vulnerability of such systems to deliberate electronic attack, and the possibility of applying "expert systems" as decision support in Air Force support and administrative functions.

INTERNATIONAL STUDIES

Jonathan D. Pollack

Jonathan Pollack, a senior specialist on East Asian political and security affairs, at RAND for 17 years, writes about the origin of Soviet studies, a field invented at RAND, and the body of international research that continues to inform U.S. policymaking.

The development of international studies, especially studies of the Soviet Union, is among the enduring accomplishments of Project RAND and Project AIR FORCE. In a real sense, Soviet studies were invented at RAND. The Air Force gave RAND an extraordinary mandate: RAND was instructed to create a field of study where none previously existed, utilizing all relevant academic disciplines, and validating this knowledge with virtually no means of direct observation or measurement—all in the context of unprecedented revolutions in military technology that redefined the very character of international politics.

Even more remarkable, this research mandate (though of undoubted value to U.S. long-range defense planning) was unconstrained by any significant guidance or oversight from the sponsor. The results therefore served national needs that extended far beyond the Air Force's immediate interests and concerns. The 1950s and 1960s in particular were an extraordinary time for international studies at RAND, leaving a singular legacy that defined the ways that policymakers, scholars, and intelligence analysts understood the primary political-military threat to U.S. interests throughout the Cold War. It is to the Air Force's lasting credit that it made such a commitment, and it is to RAND's equal credit that it seized the opportunity.

The output of this era on the Soviet Union and on other communist states was extraordinary. The RAND bookshelf is replete with the names of researchers who pioneered the social scientific analysis of Leninist systems: Nathan Leites, Margaret Mead, Philip Selznick, Raymond Garthoff, Abram Bergson, Richard Moorsteen, Raymond Powell, Merle Fainsod, Herbert Dinerstein, Abraham Becker, Alexander George, Allen Whiting, Alice Langley Hsieh, Donald Zagoria, Thomas Wolfe, Nancy Nimitz, Myron Rush, and Arnold

In a real sense, Soviet studies were invented at RAND.

Horelick stand out. Subsequent generations of analysts remain in their debt for the tools and concepts that these scholars first helped to develop.

RAND's earliest decades were driven by three unprecedented circumstances: a revolution in military technology that spawned wholly new concepts of strategy and security, a bipolar political-military confrontation without parallel in history, and a highly supportive and permissive sponsor prepared to underwrite research on an open-ended basis. This attracted exceptional talent to RAND, fostering a climate of discovery and a spirit of intellectual ferment that (despite RAND's continued analytic contributions in subsequent decades) has never again been equaled. Spurred by the singular challenges of containment and nuclear deterrence, RAND analysts provided invaluable insight into political leadership and foreign policy in the Soviet Union and other communist states, the development of Soviet military strategy and doctrine, and the organization and operation of the Soviet economy.

This body of research had an influence well beyond its immediate implications for U.S. national security interests. An array of basic methodological tools, first derived from propaganda analysis techniques devised during World War II, were refined and extended to new analytic challenges. In addition, RAND translated and disseminated unique primary-source documentation (notably, early deliberations among Soviet strategists over the implications of nuclear weapons for military strategy). The detective work needed to mine, validate, and interpret the meager array of Soviet economic data was also nothing short of prodigious, thereby helping spawn the rigorous study of centrally planned economies. RAND also pioneered in the systematic utilization of émigrés as a data source.

These analytic methods provided the natural com-

plement to the equally pathbreaking work under way at RAND on U.S. strategy for the nuclear era. They made possible realistic and informed judgments on the character of the Soviet system, the potential and constraints underlying Soviet economic and military capabilities, and the manner in which Soviet leaders defined and pursued their political and strategic interests. All this research was inescapably linked to the Cold War. RAND analysts were undoubtedly motivated by a sense of discovery and creativity, but their work was spawned by the unprecedented challenges of containment and nuclear deterrence. It is thus no surprise that Soviet analysis dominated RAND's international research.

But RAND's substantive research agenda adapted as U.S. policy needs shifted, with RAND analysis frequently providing crucial insights into these shifting circumstances. Spurred by the Sino-Soviet alliance and the Chinese intervention in the Korean War, research on China blossomed, although it never reached the scale of Soviet analysis. As insurgency became a major preoccupation of U.S. policymakers in the 1960s, attention to revolutionary warfare in Southeast Asia emerged as an important component of research for the Air Force. RAND also analyzed the implications of the Sino-Soviet conflict and the subsequent militarization of this rivalry in great depth, helping elucidate the triangular dimensions of U.S. strategy and diplomacy during the 1970s and 1980s.

Although RAND also undertook important studies on Latin America, the Middle East, and Japan, the Air Force was not the principal sponsor for this research, which relied on other government and foundation sponsors. Without an Air Force mandate comparable to that provided for Soviet studies, RAND did not develop the needed critical mass of professional skills that would have enabled sustained an in-depth analysis. RAND made its presence felt in these areas, but regions deemed less pivotal to the U.S.-Soviet competition were simply unable to elicit comparable research support. However, the rigor and depth that RAND brought to the Soviet field provided a standard against which research on other countries and regions of crucial import to U.S. interests could be measured.

The directions of RAND's Soviet analysis also underwent significant change in subsequent decades. As Soviet studies developed throughout the United States, RAND's share of the contributions to basic research on the Soviet Union diminished. Responding to the sus-

tained buildup of Soviet nuclear-weapon capabilities and the continued augmentation of Soviet military power in Europe and the Third World during the 1970s, RAND analysis increasingly focused on the options for countering the Soviet strategic challenge to U.S. interests and on better understanding the imperatives that were shaping Soviet decisionmaking. This work greatly informed U.S. policymaking, especially when the policy process was driven by unrealistic estimates of Soviet capabilities. The writings of Harry Gelman and Ben Lambeth especially stand out in this regard.

RAND's autonomy and credibility on these issues would not have been possible without the strength and durability of the Air Force's commitment to this research. This remarkable partnership spawned a field of study whose characteristics remain greatly evident today. Indeed, as the United States seeks to grasp the political, economic, and security challenges of a highly uncertain post–Cold War world, the continued relevance of decades of research undertaken at RAND is beyond dispute. RAND and the Air Force can take an understandable pride in the exceptional legacy bequeathed by this research; more than this, this body of knowledge can continue to shape the tools and analytic directions that researchers at RAND and elsewhere will take in future decades.

ARMS CONTROL

Robert A. Levine

Robert A. Levine, who joined RAND as an economist in 1957 and rejoined in 1985 after several tours in the U.S. government, describes how RAND research pioneered the concept of arms control and provided analytic support for negotiations on many international treaties.

The term *arms control* was seldom if ever heard before the mid-1950s. RAND was an early participant in the definition of this term, which broadened the classical concept of *disarmament,* pointing out that control of armaments to prevent or limit their use in war could involve arms reduction or total disarmament but, under some circumstances, might call for increasing the quantity of armaments. Above all, the stress was on *control* as such.

The central idea that took arms control out of the never-never land of proposals for large-scale nuclear and other disarmament at a time of polarized world hostilities was that arms control and deterrence were two sides of the same structure. Both were intended to prevent war, particularly nuclear war; arms controls should be designed to enhance deterrence of nuclear attack. This became basic to U.S. arms control policy thereafter.

Much of the analytical work behind the redefinition took place between Project RAND in Santa Monica and the Harvard-MIT Faculty Seminar on Arms Control in Cambridge, Massachusetts. In the late 1950s and early 1960s, analysts from Santa Monica and Cambridge moved between the two locations. From the Santa Monica end, seminal thinkers and writers Bernard Brodie and Albert Wohlstetter were major participants, as were later-to-be Department of Defense officials Alain Enthoven, Charles Hitch, Fred Hoffman, Fred Ikle, and Harry Rowen. James Schlesinger, who became Secretary of Defense in the 1970s, was a member of this RAND group from the early 1960s to his entry into the government in 1969. From the Cambridge end, Harvard Professor Thomas Schelling, who established the basic conceptual structure of deterrence theory, and Morton Halperin, who with Schelling wrote *Strategy and Arms Control,* the book that definitively tied the two together, spent year-long periods at RAND.

Going beyond deterrence theory, RAND laid the

foundations for analysis of such matters as the specifics of safe nuclear control, in which brothers Albert and Richard Latter were national experts; verification and enforcement of arms control agreements; "gaming" as a technique for examining both negotiation and enforcement; political, bureaucratic, and intellectual attitudes toward arms control; and, even at this early stage, nuclear proliferation. This period also marked the start of Soviet studies specifically concerned with arms control. Thomas Wolfe wrote extensively in this field for many years.

Although the emphasis on theory phased down as arms controllers began to wrestle with increasingly concrete problems, conceptual research has continued through the present, with Glenn Kent making important contributions.

Analysis for Negotiation

Starting in the early 1960s with the Underground Test Ban Treaty, the United States and the Soviet Union began serious but agonizing negotiations, some of which resulted in actual agreements. Many of the same researchers as in the earlier period provided analytical support for negotiations on various aspects of the Test Ban Treaty, then on the Anti-Ballistic Missile Treaty and the three Strategic Arms Limitation Treaties (SALT I, SALT II, and the prospective SALT III). In the early 1970s, William Hoehn and Russell Shaver gave substantial assistance to the Air Force on the implications of SALT.

In addition to negotiations as such, research on concrete issues of arms control ranged from the potentially destabilizing effects of multiple independently targetable reentry vehicles (MIRVs) and the stabilizing effects of conventional precision-guided munitions; through control of theater-based nuclear weapons, European attitudes on arms control, and the possibilities of regional controls in every area of the world; to such matters as control of military expenditures and the economic effects of arms control—even the effects of arms control on nuclear power plants in California.

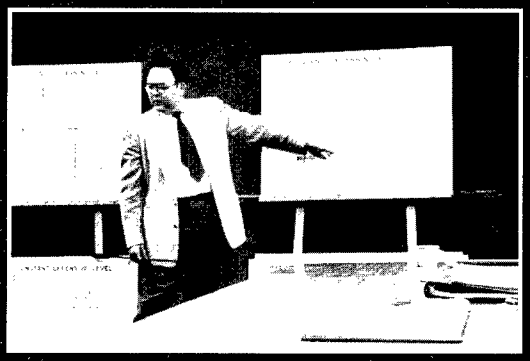
The Arms Control Breakthrough

With Mikhail Gorbachev's accession to power in the Soviet Union in 1985 and the gradual realization in the United States that extensive arms controls were becoming a serious possibility, RAND analysis made major contributions to key American policy decisions. In particular, a series of analyses of conventional arms controls in Europe, beginning with a study for PAF by James Thomson and

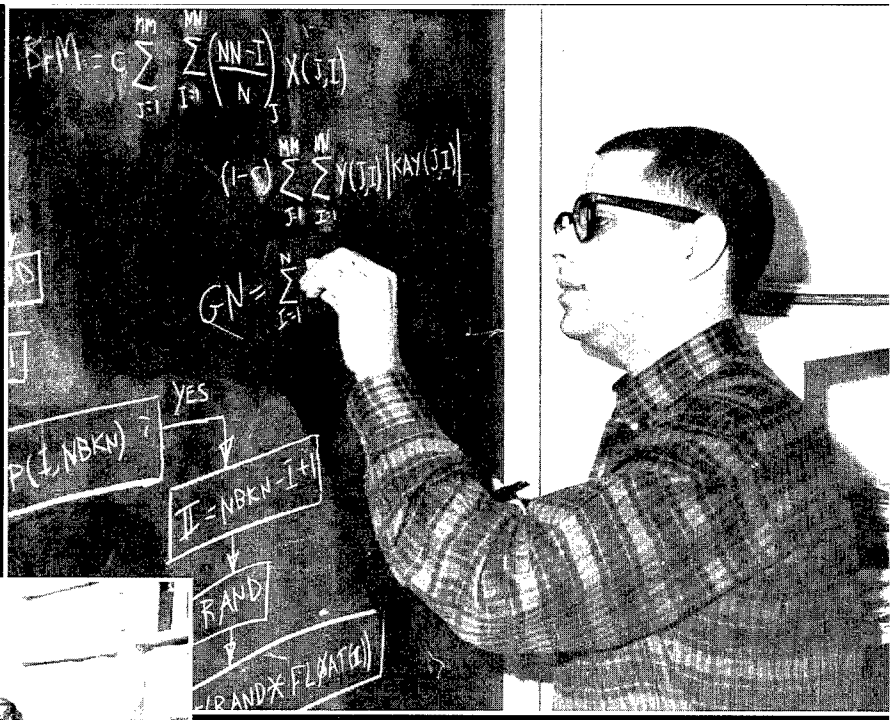
Nanette Gantz, used state-of-the-art models of combat in Europe to estimate the effects of various arms-reduction patterns on potential Warsaw Pact attacks. The results, which evaluated real rather than nominal balances between opposing forces, became the basis of the U.S. position on conventional controls and ultimately of the treaty itself. This first study was followed by others on placing limits on conventional airpower in Europe. That research, led by Charles Kelley in 1990, was incorporated first into the USAF position on air controls, then into the U.S. position and the treaty. RAND provided similar support for the difficult negotiations over reduction of strategic delivery systems.

Current Effort

Current RAND analysis of arms control focuses on the next generation of issues, mainly proliferation of nuclear and other weapons of mass destruction. A new type of game called "The Day After"—developed in large measure by Roger Molander, Peter Wilson, and Dean Millot—has participants look back from hypothesized future nuclear confrontations into their hypothetical history to ask what could have been done earlier to avoid arriving at these confrontations. Extensively played throughout the defense and broader policy communities, this game has helped initiate serious thinking about the dangerous future and the new controls that will be needed.



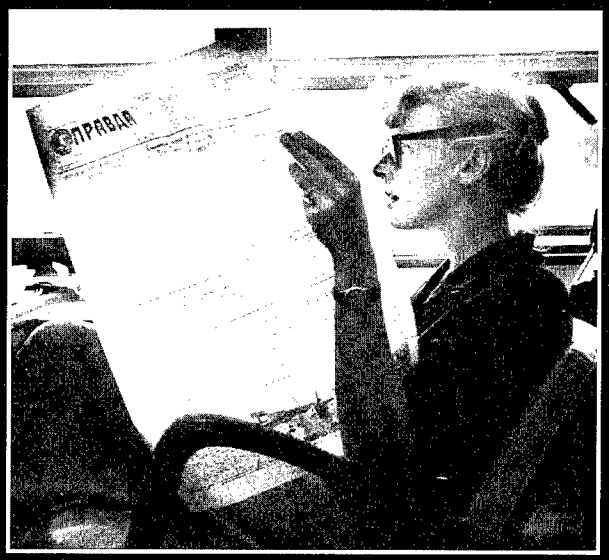
Herman Kahn



Lou "Kip" Miller

George Dantzig

Bob Buchheim



Nancy Nimitz

ANALYTIC METHODS

Paul Davis

Paul Davis, a senior scientist and RAND defense analyst for 15 years, observes that the systematic methods RAND analysts use to approach a range of problems have often had greater long-term value than the answers they came up with at a single point in time.

The years after World War II brought an explosion of interest in what is now the field of management science. Many of the basic principles and methods we take for granted today did not yet exist, and RAND led the way in developing them. Initially, the Air Force sponsored all such work, but the Office of the Secretary of Defense, the Joint Staff, the Army, and the clients of RAND's domestic research have also been sponsors in more recent years.

Ways of Approaching Problems

Analytic approaches do not usually spring from thin air. For all of its 50 years, RAND staff and consultants have tackled exceptionally complex problems that demanded new ways of thinking.

Systems Analysis

As mentioned in many of these essays, RAND's early hallmark contribution was *systems analysis:* that is, systematically examining and comparing alternative courses of action in terms of their expected costs, benefits, and risks. An early and most important contribution was recognizing that the cost of a system could not be estimated without considering the whole of which it is a part (total-force costs) and the long-term expense of producing, operating, and maintaining it (life-cycle costs).

Ed Paxson first used and named the approach in a study of strategic bombing options. His work was followed by other famous systems analyses involving air defense (Ed Barlow) and the basing of strategic bombers (Albert Wohlstetter, Harry Rowen, and Fred Hoffman). The latter led to the fundamental concept of focusing deterrence on invulnerable *second*-strike forces. About the same time, Herman Kahn and Irving Mann developed influential lectures on systems analysis, presenting ideas that were later incorporated in textbooks.

Policy Analysis

Early systems analysis focused almost exclusively on rigorously treated quantitative factors. In time, "soft factors" involving values and subjective judgments became increasingly important to RAND's analysis, and a new approach, now called *policy analysis*, evolved. Policy analysis presents decisionmakers with the costs, benefits, and risks of options through a mix of quantitative and qualitative variables and in a format (e.g., the now-familiar "stoplight charts") that lets them bring their own values and judgments to bear. Particularly notable in advancing policy analysis were Ed Quade, who wrote or edited numerous texts on policy analysis while at RAND, and Bruce Goeller, who led a major study on water-resource policy for the Dutch government that helped set the standard in the early 1980s.

Methods for Strategic Planning

Scenario Development. Characterizing possible futures is a key challenge in policy analysis. Extrapolating from the present is the easiest and most common method, but it is a prisoner of the familiar. RAND pioneered the use of alternative futures (also called scenarios) to envision a wider range of plausible futures. Among the key figures here were Herman Kahn and Olaf Helmer (who developed the now-famous Delphi technique to help bring experts to consensus). The scenario methods have subsequently become a standard feature of national security planning and advanced business planning.

In more recent years, RAND has developed other devices for encouraging divergent (i.e., imaginative and nonstandard) thinking, such as *Uncertainty-Sensitive Planning*, developed by Paul Davis and Paul Bracken in 1989, and *Assumption-Based Planning*, developed primarily by James Dewar and Carl Builder in the early 1990s. These methods encourage strategists to face up to the full dimensions of uncertainty and define strategies that seek to *shape* the future environment, *prepare* for well-recognized possible shifts, *hedge* against what might arise as shocks, and *establish signposts* warning of major shifts or shocks.

Thinking About Long-Term Competition. RAND's systems-analysis way of thinking tended to involve considerable mirror-imaging and to assume economically optimum behavior by the adversary (the Soviet Union). Partly in reaction to that tendency, Andrew Marshall developed an alternative approach that focused on the reasoning, culture, and style of our competitor so that we

Gaming in 1966. Players are Norton Kristie (left), General Ralph E. ("Zip") Koon, Milton Weiner, and Admiral Bob Lockhart.

might better understand what to expect, how to influence it, and how to win the competition. (In 1973, Secretary of Defense James Schlesinger asked Marshall to create the Office of Net Assessment.) Nathan Leites and Herbert Goldhamer were other major figures in this work.

Adaptive Planning. Recent RAND innovation has addressed the reality that *massive* uncertainty is often the rule rather than the exception in policy analysis. This reality has encouraged an *exploratory* approach to modeling and analysis in which one seeks strategies that would work well under diverse circumstances, without costing too much. These notions are central to the *adaptive planning* methods used in various ways by Paul Davis, Rob Lempert and Steve Bankes, and Richard Hillestad. Bankes and Jim Gillogly have developed special computer tools permitting exploratory analysis of "complex adaptive systems" more generally.

Game Theory. In the 1950s and 1960s, RAND was a major player in research on game theory—how opponents would use the limited information available about one another to determine the best strategy. It attracted such consultants as John von Neumann and Oskar Morgenstern, and such staff as Lloyd Shapley, J.C.C. McKinsey, Melvin Dresher, Kenneth Arrow, Martin Shubik, Rufus Isaacs, and John Williams. The famous

"prisoner's dilemma," for example, was posed and considered in depth because of its fundamental significance in so many strategy applications. RAND consultant Tom Schelling applied game theory to nuclear strategy in his classic 1960 book *Strategy of Conflict*, which he worked on at RAND and completed at Harvard.

Gaming. RAND has used human gaming routinely since the 1950s for insights about, e.g., likely action-reaction cycles in force developments and possible crisis behavior of leaders. From the 1960s through the 1980s, Milton Weiner led many operational games and Bill Jones numerous crisis games. In 1979 through 1981, Carl Builder, Jones, and Jim Gillogly conceived "automated war gaming," reflected in the late-1980s RAND Strategy Assessment System (RSAS), which permitted man-machine games in which human players and computer models could substitute for each other in representing theater commanders and heads of state. In recent years, Roger Molander, Peter Wilson, and Dean Millot have developed "The Day After" games that force participants to deal with hypothetical crises involving weapons of mass destruction, information warfare, or both. These games have been conducted with dozens of groups in the U.S. government, Europe, and the former Soviet Union.

Mathematical Programming, Systems, and Models

Systems analysis and policy analysis create enormous demands for structured thinking. As a result, they have led to development of numerous analytic methods in operations research, as well as to a variety of models and modeling systems.

Mathematical Programming and Monte Carlo Methods

RAND's work on mathematical programming has been especially influential, producing and applying such methods as linear, dynamic, stochastic, and integer programming, which are still at the heart of operations research. Another major development in the 1950s was the serious application of Monte Carlo methods on the digital computer. Herman Kahn, Ted Harris, and Andrew Marshall developed systematic application methods in the late 1940s and 1950s. Ironically, RAND's best-selling book over the years has been something called *A Million Random Digits with 100,000 Normal Deviates.* As workers in that era discovered, coming up with truly random numbers is not so easy.

Systems and Models

Over the years, RAND has developed a wide range of models and decision-support systems. These included a series of theater-level models developed by Milt Weiner (1970s); Richard Hillestad's Dyna-METRIC, a stalwart element of Air Force logistics planning (1970s), as described in the essay on logistics; Don Emerson's TSAR/TSARINA simulation of wartime operations on airfields (early 1980s); the Enlisted Force Management System (EFMS), a first-of-its-kind organizational decision-support system designed by Warren Walker (late 1980s); the RAND Strategy Assessment System (RSAS), an analytic war-gaming system designed by Paul Davis and Bruce Bennett (mid-1980s), which included artificial-intelligence models representing military commanders and political leaders in crisis, as well as military forces; a series of models in the 1980s and 1990s incorporating Richard Hillestad's SAGE algorithm, which finds game-theoretic "optimal" air force tactics for both adversaries in a simulated campaign; and the Joint Integrated Combat Model (JICM), a descendent of the RSAS focused on theater-level gaming and analysis.

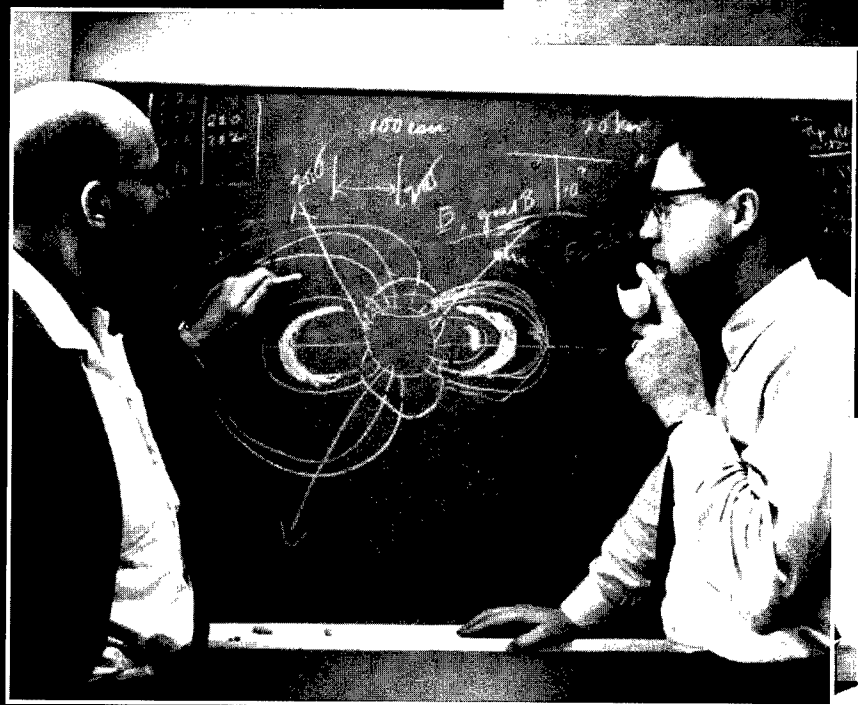
More recently, RAND has also used high-resolution simulation and families of models with different resolutions to study future forces. Randy Steeb, Al Zobrist, and Jed Marti developed an advanced distributed simulation system for assessing advanced battlefield weapons. In the early 1990s, Bart Bennett led the modeling in a major study of strategic-bomber options, requiring a family of models extending from detailed calculations of stealth aircraft air defenses to how long-range bombers contributed to an overall campaign.

RAND has also continued to make major contributions to analysis of national- and theater-level missile-defense options using the Desdemona model developed by Mike Miller, which accounts for orbital mechanics, missile characteristics, and multiplatform sensor information.

As RAND's Project AIR FORCE marks its 50th year, there has been a resurgence of innovation and an interesting contrast: Powerful interactive computers and networks are permitting sophisticated analyses of complex adaptive systems, but uncertainties about future threats and the emergence of new weapons and doctrines are motivating a return to first-order analysis designed for exploration and insight. Defense economics and systems analysis are again becoming critical as the nation faces increasingly difficult choices about how to spend scarce resources.

Willis Ware

Natalie Crawford



Harry Vestine and William Kellogg

Paul Armer

SYSTEMS TRAINING PROGRAM

Milton Weiner

Milton Weiner, who has been a defense analyst with RAND for 40 years, describes one of RAND's most successful efforts that pioneered the development of man-machine simulation, which was later instituted throughout the Air Defense Command.

Like many RAND efforts, it began with a simple question. The answer led not only to greater U.S. security against enemy air attack, but also to the creation of an independent corporation that, in time, became over ten times larger than RAND. And in between, it pioneered in the areas of man-machine simulation, concepts for organizational development, and the implementation of a large-scale Air Force training program—as well as "the modern world of interactive systems."

The time was the 1950s, and the Soviet Union had a fleet of intercontinental bombers capable of delivering nuclear weapons against the United States. The defense of the United States rested on a series of Air Defense Centers that monitored air traffic to identify possible enemy aircraft and to send interceptors out to shoot them down. Since the Air Defense Centers were "systems" of men and machines working together, the question was whether RAND could develop a training program that would markedly increase the ability of the centers to prevent enemy aircraft from getting through.

To try to answer the question, RAND's Psychology Research Department, headed by John Kennedy, decided that the best approach lay in simulating an actual center in the Systems Research Laboratory. This was a new area for RAND, if not for the entire country, because it meant simulating an actual system operating in real time and developing a training program that would put more and more stress on the system to see whether it could "learn" to handle more and more demanding situations. Although RAND was capable of building analytic models, it had limited experience in actually constructing a laboratory that incorporated a mock-up of a real system, manned by actual operators and tied into a network of other such systems.

An old pool hall at 410 Broadway in Santa Monica became the laboratory, and it was set up to simulate one

of the actual centers in the northwest United States. Marks on IBM printouts simulated the blips of radar scopes, representing the tracks of aircraft to be plotted on large plastic display boards. Actual Air Defense Center teams manned the simulated center. The teams gradually encountered more and more complicated air situations. Enemy aircraft sometimes came in groups, sometimes singly, sometimes high, sometimes low; sometimes they tried to "hide" in the friendly traffic; and they used every maneuver that the laboratory staff could envision.

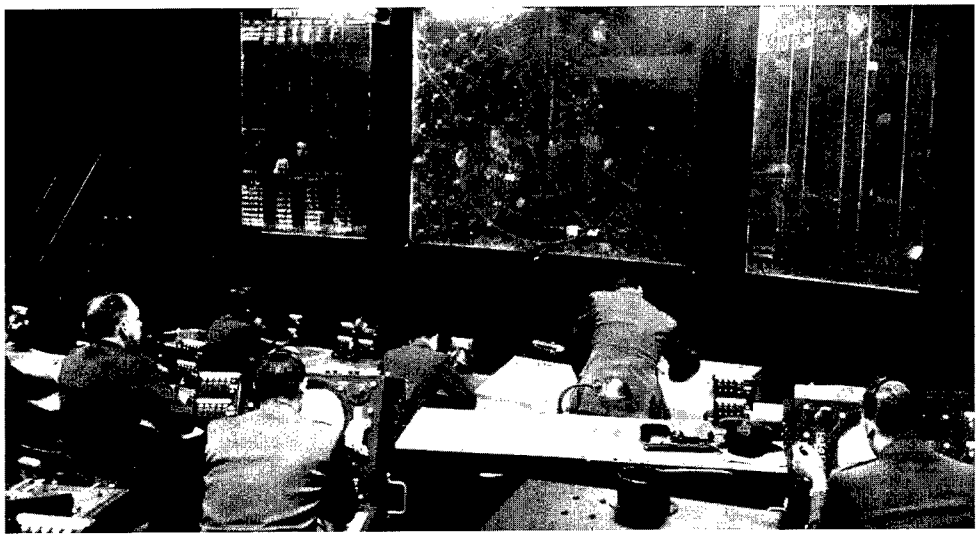
The results were impressive. Through repeated practice and the opportunity to hold debriefings, in which they discussed their "failures" and ways of improving their performance, the crews were able to handle air traffic situations far more complex than those that could actually occur. To the senior Air Force officers who viewed the simulation and saw the results, it was a clear indication that the RAND System Training Program had to be implemented throughout the entire Air Defense System.

So the experimental efforts at the laboratory had to become "production" efforts for all the Air Defense Centers. This required information about the location of each of the centers; their radar coverage; the actual air traffic in the area; and their communications with other centers, the local civilian air traffic center, and the local fighter-interceptor bases. Then, it required the development of appropriate, increasingly heavy traffic loads and the incorporation of all conceivable types of enemy air attacks. Finally, it required a training schedule and the assignment of RAND training specialists to each of the many Air Defense Centers.

To handle this major expansion of RAND activities, the Systems Development Division of RAND was established, and a major hiring program to man the division began. As a result, it could be asserted that RAND had more psychologists in its systems training program than were employed by any other organization or institution.

As the program grew in staff size, training responsibilities, and technical improvements in the simulation equipment, it became apparent that the rest of RAND would soon be dwarfed by the growth of the training program and the new responsibilities for programming the first truly automated command and control system, the Semi-Automatic Ground Environment (SAGE) system.

Faced with the responsibility for building the SAGE system, the Air Force had turned to RAND for SAGE



"Raiders" from RAND's simulated air defense center: An Air Force crew learns new defense techniques–and simultaneously helps researchers to find new training methods for other crews.

programming. RAND had already broken the necessary ground in computer-based system design, man-machine interfaces, and simulation, and its System Training Program was operational in seven divisions by 1954 (and, ultimately, in over 150 air defense installations worldwide). This meant RAND had "a familiarity with air defense unmatched by any private organization. A trusted member of the 'Air Force family,' RAND posed no security clearance concerns. . . . Most compellingly, Rand had a corner on the country's programmers." (Claude Baum, *The System Builders: The Story of SDC,* Santa Monica Calif.: System Development Corporation, 1981, pp. 22–23.)

Thus, in November 1956, a separate corporation, the System Development Corporation (SDC), was created. SDC was given responsibility for both the Systems

Training Program and SAGE programming (in conjunction with the technical developments of the Lincoln Laboratory of the Massachusetts Institute of Technology).

Initially headed by two former RAND researchers, M. O. Kappler and William Biel, the new corporation grew rapidly. Over the subsequent years, SDC expanded into a number of research and development areas in contracts with the Strategic Air Command, the U.S. Navy, many other government organizations, and many private organizations, finally going "public" in 1980. Meanwhile, at RAND, the original research on man-machine systems and on simulation techniques was extended into new areas, resulting in the Logistics Simulation Laboratory (LSL), the Tactical Air Command Control Systems (TACCS) Simulation, and the Military Operations Simulation Facility (MOSF).

Thankfully, the nuclear attacks by Soviet bombers that were the basis for the initial training program never occurred. But had they done so, the implementation of the RAND-developed Systems Training Program and the SAGE system unquestionably would have saved millions of lives and billions of dollars in physical damage. ✦

DEFENSE ECONOMICS

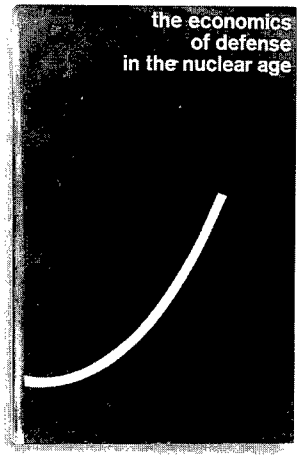
Charles Wolf

Charles Wolf, senior defense economist and corporate fellow in international economics at RAND, writes about the profound influence of RAND's application of economic analysis to military decisionmaking.

From the formation of RAND's economics department in 1948 to the present, defense economics—broadly interpreted to encompass both the economic aspects of defense and the defense aspects of the economy—has been a significant and sustained component of RAND's research portfolio for the Air Force. Within that portfolio, the prominence of defense economics has varied. In the 1960s and the early 1970s, its prominence rose with publication of *The Economics of Defense in the Nuclear Age*, by Charles Hitch and Roland McKean, which grew out of work they and their colleagues in the economics department had done in the 1950s. From that pioneering work emerged the concepts and processes that composed the Planning Programming and Budgeting System (PPBS) for rationalizing the allocation of defense resources among competing programs, procurements, and services. Noteworthy contributors to the development of PPBS were Alain Enthoven, Harry Rowen, Arthur Smithies, and Dave Novick, whose early work had suggested practical methods for analyzing the costs of weapon systems and alternative force structures.

Also in the 1960s, the quintessential economic paradigm of maximizing outputs from given inputs (or, equivalently, minimizing the costs of specified outputs) pervaded much of RAND's work on other issues of defense economics, such as the sharing of burdens in NATO (by Malcolm Hoag and others), the real economic costs of conscription compared to those of an "all-volunteer force" (Bill Meckling, Armen Alchian, and others), the economics of national security (Jim Schlesinger), and applications of linear programming in economic analysis (Bob Dorfman, Paul Samuelson, and Bob Solow). Parallel developments in system acquisition policy and practice, another important dimension of our work on defense economics, are discussed in a separate essay by Giles Smith.

Defense economics also was a major contributor to RAND's important methodological development of systems analysis (as described in other essays) through the work of Charles Hitch, Ed Quade, Gene Fisher, Andrew Marshall, and others.



In the latter half of the 1970s and the first half of the 1980s, the prominence of defense economics in RAND's research portfolio receded somewhat, while PAF placed greater emphasis on nuclear issues, ICBM accuracy, strategic and tactical forces, space defense, precision-guided munitions, and other related priority issues in which strategy and technology were especially salient and economic considerations were subsidiary.

From the latter half of the 1980s to the present, defense economics—again, broadly construed in RAND's style of work in the field—has received renewed attention. This increased prominence seems likely to wax still further in light of the growing pressures on the defense budget and of the increasing importance of interactions between civil technology and military resource allocation issues and between the civil and military sectors of the economy. These issues include, for example, the changing size and character of the defense industrial base, the adequacy of that base, the issue of reconciling increased concentration (through mergers and acquisitions) in the defense industry with maintenance of competition, and the expanded opportunities for the military to "piggyback" on civil industry and technology—in such fields as computer software and hardware, telecommunications, and sensors. Work on these matters has been and is being pursued by Frank Camm, Mike Kennedy, Bob Roll, Dennis Smallwood, and others.

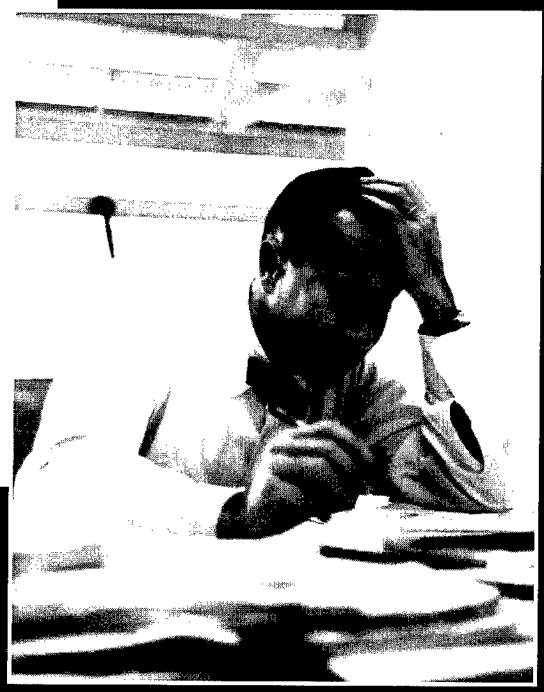
Also, in the 1980s and into the first half of the 1990s, research in defense economics at RAND has extended to other countries (for example, work on Korea and Japan by Norm Levin and Arthur Alexander); the costs and benefits of the then-Soviet empire; defense conversion in Russia and the Ukraine; long-term trends that link the economies and the military sectors in the United States, Germany, Russia, China, Japan, India, and other countries; and analysis of the economic dimensions of national security (Dick Neu and Charles Wolf).

In the current and emerging international security environment, there is no single, overriding military threat as there was during the Cold War. Instead, there are many small, highly uncertain potential threats. In this new environment, the national economy of the United States is increasingly linked to the world economy, and the major societal problems in the United States are closely linked to the performance of the national economy. In these circumstances, the scope of defense economics in the next 50 years will probably grow because of the expanding breadth and intensity of the connections between defense and economics. In this world, defense may be the "cart" and the economy may be the "horse," rather than the other way around, in shaping U.S. military forces and policies for their employment.

Amrom Katz

Dick Bellman

Cliff Shaw



Charles Wolf

MANPOWER

James Hosek

James Hosek, a defense analyst with 23 years at RAND, describes RAND's groundbreaking work helping the Air Force determine future manning requirements and developing models for personnel management.

By the end of World War II, with a large peacetime force in the offing, the founders of the Air Force recognized a fundamental challenge to its success: to ensure the supply of high-aptitude recruits, the retention of trained personnel, and the efficient utilization of this costly, scarce resource. Without highly skilled technical and professional personnel, the Air Force simply could not operate. RAND's manpower research helped the Air Force meet this challenge.

Determining Manpower Requirements

In the late 1960s, RAND began a series of studies on determining manning requirements. RAND's thinking emphasized that requirements should be determined by relating inputs to desired outputs. This approach has spawned a rich legacy of manpower and logistics research, both simulation models and empirical studies. RAND's Logistics Composite Model derived skill-mix requirements by relating the distributions of aircraft sorties, component failure rates, and repair times to the specific skills needed to make the repairs. Varying the number of personnel and their skill mix would change the repair capacity and turnaround time. Thus, analysts could explore the robustness of alternative manning levels and mixes for meeting mission objectives.

Another early contribution came from a 1968 study that analyzed the relationship between flying hours and unscheduled "fix it" maintenance. Planners had generally assumed that more flying hours would mean more unscheduled maintenance, but the research challenged that relationship. Clearly, standby repair capacity was needed, but the size and manning did not depend on flying hours.

Moving to an All-Volunteer Force

Given its need for highly skilled personnel, the Air Force

was seriously concerned when the draft became a top policy issue. What would the end of the draft mean for the future supply of high-quality personnel? What would the near-term consequences be of having fewer high-quality, draft-induced recruits? By 1970, the Air Force had asked RAND to look into the consequences of moving to an all-volunteer force. A RAND study confirmed that, in the near term, Air Force recruit quality might suffer. However, the study also found that this effect would most likely be offset by the increasing size of the recruit-aged population, a smaller military force after Vietnam, and possible increases in military pay.

The end of the draft was also problematic for the Air Reserve forces. At that time, 73 percent of Reserve personnel were non–prior service personnel, many draft induced. An elegant theoretical and empirical analysis concluded that the supply of new recruits to the Air Reserve could, as feared, decline sharply. Further work estimated an enlistment shortfall as great as 66 percent. The research indicated that much of the shortfall could be offset by a pay increase, but how much vulnerability remained? A companion study showed, somewhat surprisingly, that even a 33-percent shortfall would decrease flying capability by only 5 percent. Most of the work could be done by mid- and high-skill personnel already available.

Meeting Medical Manpower Requirements

Potential doctor shortages have posed another manpower challenge for the Air Force. RAND studies identified three innovative means for addressing that problem. First, RAND studies led to an expanded role for physicians' assistants, which continues today, and effectively reduces the manning requirements for physicians. Second, medical-school scholarships proved to be key to assuring the Air Force a long-run supply of physicians.

Third, even with these innovations, the Air Force still faced potential wartime shortages of physicians in certain specialties, particularly surgery. Relying on special surveys, expert panels, and an interdisciplinary approach, researchers constructed a model to analyze the Air Force's peacetime and wartime requirements for physicians. They found that the physicians needed to meet peacetime demands, e.g., internists and obstetricians, could handle many steps in field surgery operations, thereby allowing surgeons to concentrate on the most difficult steps.

USAF air traffic controllers at work

Developing Personnel Management Models

PAF has contributed a major body of work on personnel management models. Starting in 1971, researchers used linked data to develop an empirical, Markovian model of personnel flow, opening the way to a flood to improvements. Work in the early 1970s laid out the logic for several models for officer personnel management, giving serious treatment to promotions, grade constraints, and early outs. This work prompted the development of a series of dynamic, disaggregate, behaviorally driven, and increasingly capable models for officers and enlisted personnel over the next 20 years.

A 1974 RAND critique calling for the inclusion of an economic model of retention decisions was followed up with development of a pathbreaking dynamic retention model. This research was influential in the passage of the Defense Officer Personnel Management Act. It also has been the basis for subsequent RAND analyses of the structure of military compensation, the retirement system, and the design and effects of separation pay, which

was implemented in the 1990s to help achieve the defense manpower drawdown.

In the late 1970s, researchers studied the existing and preferred connection between the Air Force's personnel management system and its manpower system, which governs manning requirements and authorizations. This project led directly to the development of a new enlisted force management model in the 1980s. Now in Air Force use, this model is dynamic, based on behavior, and uses individual data and achieves the modeling goals set at the outset of PAF's personnel management research.

PAF's manpower research builds on the imagination and effort of many dedicated researchers. These researchers forged a close working relationship with the Air Force, ensuring that the design and conduct of research projects maintained a direct correspondence to the key issues confronting the Air Force and, at the same time, dedicated themselves to building new tools and performing innovative, high-quality research. A brief list of major contributors would include Theodore Donaldson, Andy Sweetland, Al Cook, John White, Bernard Rostker, Robert Shishko, David Chu, Robert Roll, Susan Hosek, John Merck, Louis Miller, Herbert Shukiar, Glenn Gotz, John McCall, Craig Moore, Warren Walker, Grace Carter, Marygail Brauner, and Peter Rydell—yet many others also played crucial roles.

LOGISTICS

Irv Cohen and Mort Berman

Irv Cohen and Mort Berman have been major contributors to RAND's logistics research for more than 30 years. Their essay describes the ongoing contributions RAND has made to improving support for Air Force operations in peacetime and in war.

RAND's contributions to the understanding of logistics are so numerous and wide-ranging that we can mention only a fraction of them—and only a handful of key people—in a short essay. In the last 50 years, up to 60 analysts were working on logistics research at any given time, a great many of whom made lasting contributions to the field. The concentration of effort and successful liaison with the Air Force that this required would not have occurred without the guidance of such senior leaders as Charles Zwick, Murray Geisler, James Peterson, Richard Van Horn, Steve Drezner, and Michael Rich.

It all began in the 1950s. The Air Force called for RAND's expertise to improve support for their operations. The effort moved along two fronts. One body of work, which predominated in the early years and continues to the present, has studied how to improve specific elements of the logistics system—spare-parts policies, for example—to improve efficiency and reduce cost. A second, more recent, body of work has focused on increasing the flexibility and responsiveness in the entire logistics system to help mitigate the impossibility of forecasting resource demands with any precision. Without the broad spectrum of detailed studies that forged our understanding of how the vast system worked, Project AIR FORCE could never have embarked on the ambitious systemwide analyses of the last 15 years.

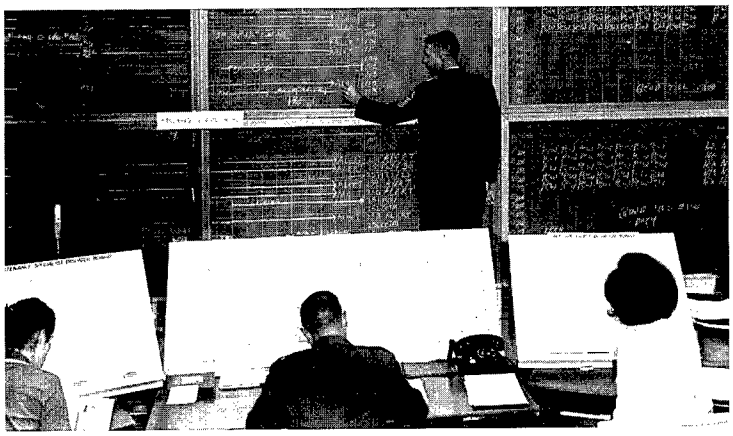
Some of RAND's most influential work falls into the first category, including studies of aircraft maintenance management at base and depot, inventory theory, spares and repair management, and reliability of aircraft avionics systems. Much of the work in the 1950s and early 1960s was conducted in RAND's Logistics System Laboratory, a kind of test facility for new logistics concepts. One influential laboratory study, led by Irv Cohen, simulated the maintenance procedures used on air bases and showed the benefits of introducing

Analyzing maintenance data in RAND's Logistics System Laboratory in the early 1950s—before the computer era

computer-supported maintenance management control—which eventually formed the basis for the Air Force's Maintenance Management Information and Control System. For 10 years, this laboratory's efforts involved up to 40 members of the Air Force at one time working alongside RAND staff in the kind of intense collaboration that has marked our logistics work from then until now.

A major breakthrough occurred at RAND in the late 1960s with the work of Craig Sherbrook and others, who developed a mathematical technique for determining optimal inventory levels at both the base and the depot. This technique—called METRIC—included methods to improve the forecasting of demands for spare parts in peacetime. METRIC allowed an Air Force base to achieve higher performance at much less cost for spares in an era of large stockpiles and relatively predictable peacetime flying environments. METRIC concepts are still used widely by military services and industries around the world.

Further progress in spares and repair management was made in the early 1970s, when RAND began to



Improving manual maintenance scheduling (1962), before automating the process

focus more emphatically on the problems of logistics support in wartime, when flying activity is intense and demands for resources are most critical. RAND proposed a number of alternative support arrangements to ensure continuous support, including centralized in-theater repair, which was adopted by the Air Force. The wartime focus prompted Dick Hillestad to develop Dyna-METRIC by adding the dimension of dynamic scenarios to the steady-state approach of METRIC to evaluate the effects of support alternatives on aircraft sortie rates. This model, updated several times, became the principal analytic tool for all of RAND's work in spares and repair management. One of the later versions was embedded in Air Force–standard systems. PAF is now preparing the next generation of Dyna-METRIC, with yet more enhanced representation of uncertainty, which we will recommend to the Air Force for routine operational use.

In the 1980s, PAF returned to a problem that had troubled researchers, such as Bernice Brown, in the 1950s: the inability to predict the demand for spare parts with confidence. Gordon Crawford studied the

repair records on the F-15 in peacetime and found wild fluctuations in demands—much greater than was generally realized—that could not be explained by such factors as flying time. This finding underscored the importance of a more-responsive depot repair system. Recognizing that more aircraft could be kept flying if a means were found to give priority to certain spares slated for repair, Jack Abell and others developed and demonstrated DRIVE, a model designed to help depot repair managers set repair and distribution priorities by measuring their effects on aircraft availability. The Air Force is now using this model widely.

At the same time, Hy Shulman led research efforts to determine how to field effective avionics systems by integrating relevant policy on acquisition, operations, and logistics. This work helped the Air Force break through barriers separating functional areas and reinforced the value of cross-functional, systemwide analyses.

Building on the accumulated understanding of all this earlier research, PAF's logistics analysis since the early 1980s has called for even broader systemwide changes. This body of work emphasizes the need to take uncertainty into account explicitly in formulating policies and designing systems—not just the statistical uncertainty of demand rates but the external uncertainty of the state of the world. A major undertaking known as CLOUT (Coupling Logistics to Operations to meet Uncertainties and the Threat), led by Irv Cohen, urged the Air Force to rely less on large warehouses of assets based on poor forecasts and to rely more on rapid resupply from depot repair and on lateral repair and supply. CLOUT reinforced the findings of an earlier study, led by Mort Berman, that assessed the benefits of mutual base support in the European theater. That study focused on wartime-induced uncertainties and demonstrated both the necessity and the cost-effectiveness of investing in a small fleet of aircraft dedicated to moving spare parts quickly among the bases of the European theater. These findings led to establishment of the European Distribution System.

This research into the effects of uncertainty pointed to many characteristics of the current system that needed to be changed to achieve the flexibility necessary for rapid resupply to meet unanticipated demands. PAF's most recent major effort—lean logistics, led by Ray Pyles—takes these initiatives even further by drawing on modern business practices, particularly the "lean" production practices that the U.S. auto industry adopted

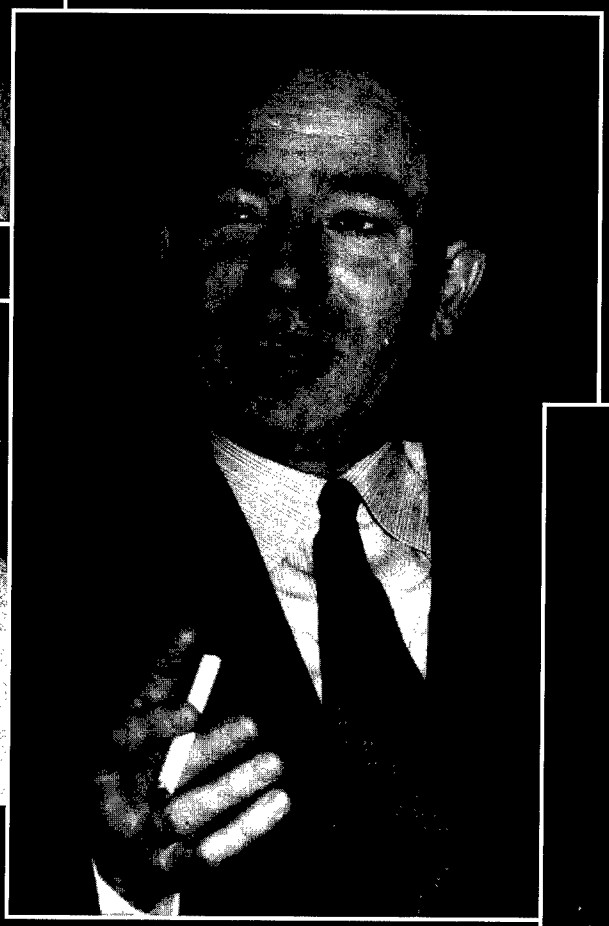
from the Japanese. The new system represents a fundamental shift from the Air Force's current "mass-production" model and calls for a more responsive, "market-driven" culture that (1) gives the combat command control over the system; (2) streamlines distribution, depot repair, and manufacturing; and (3) uses the competition between contract and organic sources of support to motivate improvement. Early findings suggest that the lean logistics system provides more robust support at dramatically less cost across a full range of situations. One aspect of lean logistics—dramatic increases in the speed of spare parts moving among repair, inventory, and operating locations—is now being pursued by the Air Force.

The close working relationship between RAND and the Air Force is perhaps nowhere better illustrated than in logistics research. Helping the Air Force implement the new lean logistics system will require the same close liaison with members of the Air Force at all levels that has characterized our successful partnership over the last 50 years.

Charlie Hitch

John Kennedy

Herbert Goldhamer



Hans Speier

John von Neumann

ACQUISITION POLICY

Giles Smith

Giles Smith, a defense analyst at RAND for 40 years, describes how RAND research has contributed to a greater understanding of successful military research and development programs.

Although weapons and threats have changed over the years, much of PAF's work for the Air Force on acquisition issues has centered on one enduring theme: how to organize and manage a successful research and development program involving exceptional challenges and risks as the attempt to gain an edge over the enemy pushes the developers into uncharted areas of complex technologies. As the resulting weapon systems became more complex and expensive and the number of new starts declined, it became both more difficult and more imperative to make each new program successful.

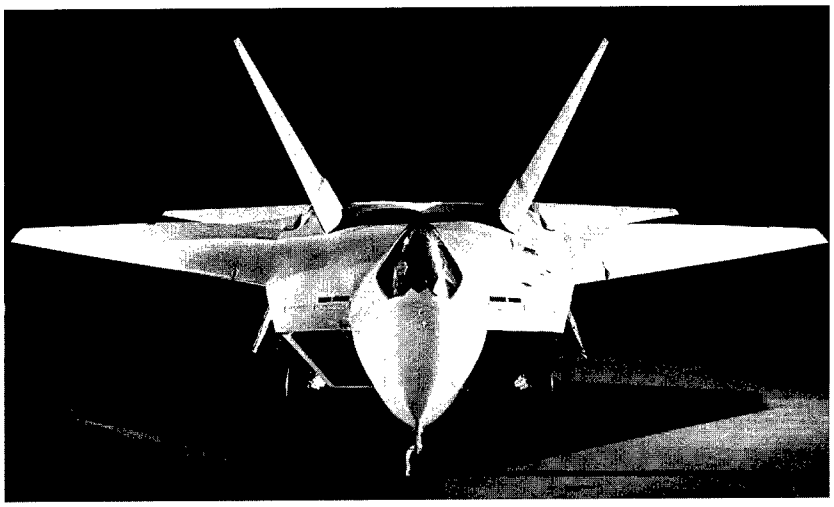
RAND's approach to this problem has been highly empirical. We have carefully examined a wide variety of acquisition programs, whether successful or not, to create an evolving base of knowledge that managers can draw from when designing new acquisition programs. The first such study was issued almost 40 years ago when a "new wave" of theory was arguing that alternative technologies and design concepts could be thinned out early in development through careful analysis, thus allowing efforts to focus on a single "best" design. Burt Klein and a group of economists and engineers challenged that view in a seminal report, *Military Research and Development Policies* (1958). Based on a review of many development programs over the previous 20 years, the report concluded that the uncertainties and risks inherent in such programs seriously limit the effectiveness of early, analysis-based selection. In fact, a considerable amount of competition and duplication was frequently desirable:

> A good development policy will frequently have two or more alternatives under development early in a program, and will call for a decision about which major components will be integrated into the final system only after initial test data have provided information about the relative merits of the alternatives.

That theme of coping with technical uncertainty and risk by use of multiple, competitive sources has continued to be reflected in other strands of acquisition research. One strategy involves the use of prototypes to gain confidence and reduce technical risks early in a program. During the late 1960s, that question was raised regarding the then-emerging F-15 fighter program. RAND recommended that competitive prototypes should be built and tested prior to start of full-scale engineering development. The Air Force disagreed and proceeded with a sole-source development, which was successful. The same question was raised nearly 20 years later during the Advanced Tactical Fighter program, and RAND again argued in favor of a prototype phase. In that case the Air Force agreed, leading to the YF-22 and YF-23 systems being built and tested.

A parallel, and critically important, line of research has focused on developing methods for estimating the cost consequences of different acquisition strategies. Dave Novick and others at RAND pioneered the development of parametric cost-estimating relationships that could be used not only to estimate the cost of a particular system but to explore alternative system concepts and acquisition strategies. This work has continued over the years; models have been updated to reflect new technologies and the changing institutional environment in which weapon acquisition programs are managed. In addition to developing cost-estimating methods, RAND has often provided "independent" cost estimates of proposed new weapons. Such estimates were usually higher than those the developers offered, leading to contentious debates, but the RAND estimates have almost always proved closer to the actual costs. Building on that experience, the Office of the Secretary of Defense inaugurated a special staff in the late 1960s that was charged with preparing such independent cost estimates and with sustaining development of estimating methods and associated databases.

Another recurring issue has been over when competitive dual sources are warranted for the production phase of a weapon system. Since the end of World War II, the vast majority of systems have been produced by the same firm that performed the development. The resulting quasi-monopolies have received considerable criticism, especially from the Congress. By assembling information on numerous programs, including a few that had used competitive dual sources, RAND developed some decision tools that could be applied to future systems.



The YF-22 prototype for the F-22

Those tools were applied to dual-source issues for several air-to-air and cruise missile programs and in response to a direct congressional mandate to consider such competition for production of the B-2 bomber. Contrary to widespread expectations that competition is always beneficial, our research shows that using competitive dual sources of weapon-system production is usually justified as a cost-saving measure only for items with high production quantities, such as munitions.

In recent years, a new theme has emerged in RAND acquisition research, regarding policies that the Air Force and other government agencies might be justified in using to ensure continuation of a vigorous industrial base, together with an in-house management infrastructure, capable of effectively and efficiently responding to future military needs. As the defense budget decreases, fewer new systems are started, the industry consolidates, and government "buyer" staffs must shrink. Can this process occur without serious loss of critical capabilities? Several recent and current RAND studies are addressing these issues.

Finally, we note that the RAND research in acquisi-

tion policy and practice started many years ago with an analysis of strategies for dealing with risks and uncertainties. Bob Perry wrote numerous reports describing the different strategies and how they worked in different situations. That theme has resurfaced recently in the publication of a major study on barriers to managing risk in large-scale weapon-system development programs. In that study, Tom Glennan and his colleagues reviewed a number of recent system-acquisition programs and concluded that considerable progress has been made in establishing broad policies governing weapon acquisition. But even when operating under those policies, achieving a successful weapon acquisition program remains challenging. In large part, this is because the advocacy-oriented process inherent in our political system tends to limit the manager's ability to manage the risks inherent in many acquisition programs. Continuing RAND research will examine further methods for refining and improving our overall organizations and methods for designing and managing advanced weapon-system acquisitions.

THE POST–COLD WAR WORLD

David Ochmanek

David Ochmanek is a strategist and defense analyst who has recently returned to RAND after serving as Deputy Assistant Secretary of Defense for Strategy. He describes highlights of PAF research into the dynamics and military challenges of the post–Cold War era.

The wide scope of PAF's research meant that it was well-positioned to help the Air Force and the nation adjust to the post–Cold War environment. Indeed, PAF's focus had begun to shift away from Cold War problems well before the Soviet Union collapsed in 1991.

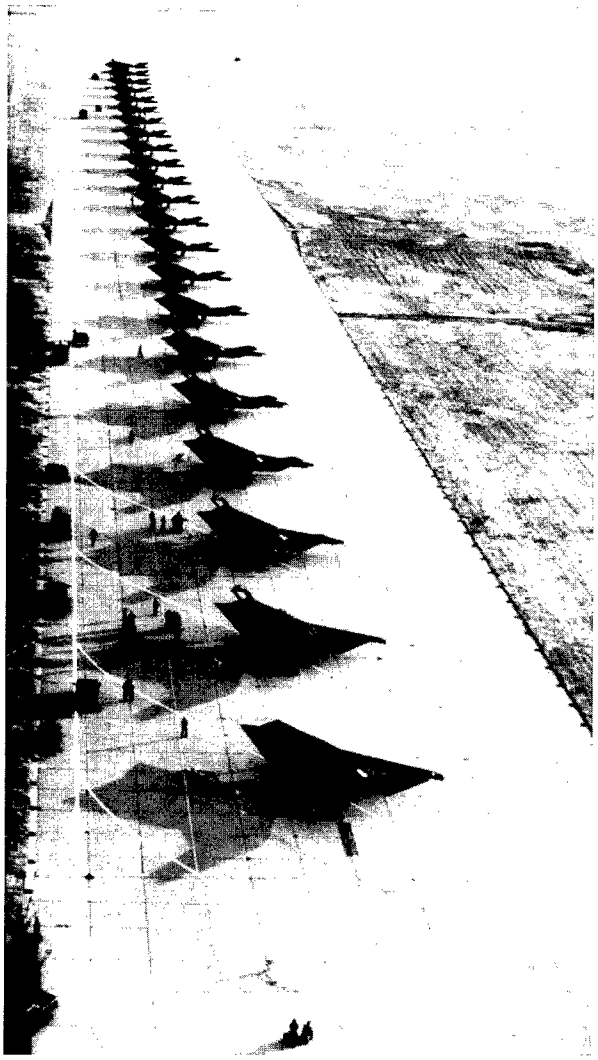
National Security Strategy

In 1989, seeking to help the Air Force broaden the basis of its force planning, PAF examined a range of possible security environments for the following 20 years. The study concluded that U.S. force planning needed to give more emphasis to "peripheral" contingencies, mainly in the oil-producing areas of the greater Middle East. It also suggested that difficulties in gaining access to overseas bases would make long-range attack capabilities, especially those offered by heavy bombers and long-range standoff weapons, increasingly attractive.

Building on this work, PAF began to examine the problem of defending key oil facilities in the Persian Gulf against regional aggressors. Consequently, in the fall of 1989, PAF developed war games involving Iraqi aggression against Kuwait and Saudi Arabia. These prescient efforts provided a strong foundation for later work led by Zalmay Khalilzad in direct support of the Air Staff during Operation Desert Storm.

PAF also contributed to the development of U.S. national security strategy for the post–Cold War world. PAF studies in 1990 pointed to the need for a post–Cold War strategy of U.S. engagement and leadership. This work highlighted important roles U.S. military power could play in support of such a strategy and showed how U.S. contributions to the security of partner nations would bring increased cooperation across the entire spectrum of international issues.

Another PAF contribution that has helped guide defense strategy and practices in the 1990s is the strate-



Nevada-based F-117 Stealth Fighters line up at Langley Air Force Base, VA, for an overnight stay before deploying to Saudi Arabia.

gies-to-tasks framework. Based on PAF research done by Glenn Kent and others in the 1980s, this approach was developed to lend conceptual and analytic rigor to strategy development and force planning. Because it enables analysts to assess trade-offs among fielded and projected military forces by linking them to national objectives, the strategies-to-tasks framework has gained wide acceptance in the Air Force and the Department of Defense, including a number of the working groups within the Joint Warfighting Capabilities Assessment process sponsored by the Joint Chiefs of Staff.

Countering Weapons of Mass Destruction

Recognizing that weapons of mass destruction held by regional adversaries could seriously threaten future U.S. theater operations, PAF researchers examined the problem from various perspectives. A series of "Day After" policy games, developed by Roger Molander, Peter Wilson, and Dean Millot, explored the challenges posed by small numbers of nuclear weapons in a range of post–Cold War crisis and conflict situations. Beginning in 1991, David Vaughn and others in PAF also assessed ways of defeating mobile, tactical ballistic missiles, concluding that the most promising approaches were to

attack mobile missile launchers right after launch and to develop capabilities for intercepting missiles in the boost phase.

Improving Overall Effectiveness

By the late 1980s, PAF researchers recognized that the long-range bomber force should be structured primarily to meet the demands of large-scale conventional conflict (rather than for nuclear use). This insight inspired a series of studies led by Glenn Buchan, beginning in 1987, about new ways the bomber force might contribute to U.S. power-projection capabilities. Since then, PAF has identified priorities for advanced bomber weapons, including long-range standoff missiles and others. Recent work by David Frelinger and Joel Kvitky has introduced new operational concepts to maximize the effectiveness and flexibility of the entire bomber force.

In 1991 and 1992, much of PAF's work on potential scenarios culminated in a broad-gauged assessment of the Air Force's future force structure and investment priorities. In *The New Calculus*, PAF researchers led by Chris Bowie and Fred Frostic argued that modern, land-based air forces are uniquely suited to meeting a number of critical strategic needs in the post–Cold War era. *The New Calculus* endorsed U.S. force reductions along the lines of the subsequent Bottom-Up Review, but also underscored the necessity of modernizing key portions of U.S. forces.

The New Calculus and other studies recognized that dramatic improvements in information-related technologies offer potential opportunities but also entail risks and costs. Recent PAF research has been helping the Air Force understand its choices and the trade-offs among them. Projects have focused on everything from improved surveillance capabilities and better satellite communications to military uses of space and the "value of information" in various types of operations.

Other notable research has included efforts to enhance airpower's effectiveness against light and irregular forces (Alan Vick), to maximize the psychological effects of airpower on enemy forces (Stephen Hosmer), and to assess strategic options available to adversaries seeking to blunt U.S. power-projection operations (Ken Watman). PAF also sponsored early, pathbreaking work that helped policymakers shape the post–Cold War strategic landscape. For example, PAF research influenced U.S. and NATO positions on tactical airpower in the Conventional Forces in Europe talks. And PAF was

among the first to sample opinion in the former German Democratic Republic—work by Ronald Asmus that affected the "two plus four" talks that led to German reunification.

Recent PAF research has not focused exclusively on the geostrategic environment, strategy, and military operations. Working with the Air Staff and Air Force Materiel Command, PAF is helping the Air Force adopt managed competition, just-in-time inventory management, and other concepts that will result in a leaner, yet more responsive, logistics system. And in *The Icarus Syndrome*, Carl Builder explored changes in airpower theory over the decades and assessed the effects of these changes on the institutional cohesion of the Air Force. This work concludes with provocative suggestions about mission, vision, and airpower theory for the Air Force of the post–Cold War era.

THE NEW CHALLENGE

Gen Michael P.C. Carns (USAF, Retired)

Gen Michael Carns served as the Vice Chief of Staff of the Air Force (1991–1994) and Director of the Joint Staff during the Gulf War. This passage is taken from a keynote address he delivered at a dinner for the RAND Board of Trustees and invited guests to celebrate PAF's 50th anniversary. General Carns began his remarks by noting RAND's contributions to the successful conclusion of the Cold War. What follows are his final remarks.

It is very clear that the strategy of containment, so persuasively argued by George Kennan in 1947, provided the vision and the perspective that we all understood and systematically turned into the diplomatic, economic, and military lever that eventually defeated the Soviet Union.

What is the equivalent idea for today? What is that vision that defines the path ahead? What is that concept that we can operationalize to protect the national security of America against the newly emerging set of threats?

First, let's quickly dispose of what the task is not. This is not the time for focusing research efforts on the refinement of force structure or debating the merits of alternative logistics resupply concepts—certainly two of many important microquestions, but none of these command first priority.

Instead, now is the time for the big picture—time for defining tomorrow's security perspective and the principles that will guide our efforts. And as we struggle to sketch out that picture, we will find no clear navigation points to help us with our lines. . . .

The Air Force Chief, General Ron Fogleman, is on the right track. He has asked RAND to contribute to the collective understanding of what the Air Force of the future should be. . . . Once we are able to visualize tomorrow's strategic perspective, we have the will, determination, and dedication to operationalize it and to organize, train, and equip the right force to do the right things to fulfill our national security responsibilities. . . .

RAND prides itself in having the special skill sets necessary to properly formulate the problem and making sure that the right question has been asked. You—RAND—have done it ably in the past; you have

the talent to do it now and the grit and determination to make it happen in the future. This can be your finest hour.

As the Chairman, General John Shalikashvili, has reminded us on more than one occasion, we need professionals who can name that tune after the first two notes. Your job—RAND—is to help us identify that tune.

April 11, 1996
Washington, D.C.