Chapter 8
National Security Systems Research and Close Support

The pronounced tendency in the United States to fund a significant part of its research through its national security agencies means that a similarly significant portion of SRI research contracts come out of that part of our government. While much of the work described elsewhere in this book had such sponsorship, its applications were not just for the military. In this section we will cover some of those research areas whose applications are unambiguously important to the DoD mission or to civil defense. Because the DoD sector's share of SRI revenue has at times approached 60 percent, there are, of course, many such tales to tell. Given the obvious constraints, we will treat only ten or so here.

SRI's Early Antenna and Communications Efforts

Electromagnetic wave propagation and radio communications systems played an important part in the early development of SRI. The motivation came from an increased need, in both military and commercial aviation, for continuous in-flight communications and navigation. A critical part of that capability was greater attention to the design and measurement of aircraft antennas. For example, increasing flight speeds in the 1950s meant that the aerodynamic drag imposed by existing antennas was reaching the equivalent of 90 horsepower at 300 mph and would go to over 700 horsepower at 600 mph.[A] Something needed to be done. Also unfolding was the very large increase in air traffic in the United States. The number of airplanes flying had increased from 23,000 to 127,000 in the 12 years ending in 1953, a change possible only through better aviation electronics. For example, such electronics had enabled 330,000 instrumented landings in 1952, yet the cost of electronics for a large jet bomber could run over $300,000. Radio and navigation systems aboard both commercial and military aircraft were coming to represent a very significant fraction of the cost of the plane.[B]

SRI became engulfed in the problem. In the area of antenna design, two solutions emerged: (1) conformal or surface-fitting antennas to reduce drag and (2) antenna multi-couplers and tuners that, by permitting more than one transmitter/receiver per antenna, would reduce the number of antennas required. The considerable need for this work led early to the establishment of an aircraft antenna laboratory at SRI called the Aircraft Radio Systems Laboratory. By 1950 SRI had built an antenna range high atop one of its flat-topped Menlo Park buildings to measure the radiation pattern of aircraft antennas to be used on high-performance aircraft. SRI conducted virtually all of these investigations using scale models. The models were accurate enough that the distribution of currents over the body frame could also be measured to help understand their impact on the total radiation field from the aircraft. By 1954 SRI had seven model ranges in operation both in Menlo Park and at its Mount Lee site in Los Angeles.

Figure 8-1 shows a part of one antenna range on which the radiation pattern of an antenna-fuselage combination could easily be measured. This pattern gives the true indication of the utility of an antenna design because it depicts the far or long-distance field of the aircraft's radiation distribution. The other part of Fig. 8-1 shows the use of a probe to assess the distribution of radio-frequency electrical currents on the metal fuselage itself. SRI's conformal antenna design plus the associated electronics worked so well that it came to be used on 26 different types of aircraft.[C]

The new technology behind the multi-coupler was largely centered in the electrical matching circuits that lay between the transmitter and receiver and the antenna. SRI's innovation consisted of an automatic tuning of the antenna to the characteristics of the selected transmitter or receiver, regardless of the antenna's immediate properties, which meant that conditions such as icing could be

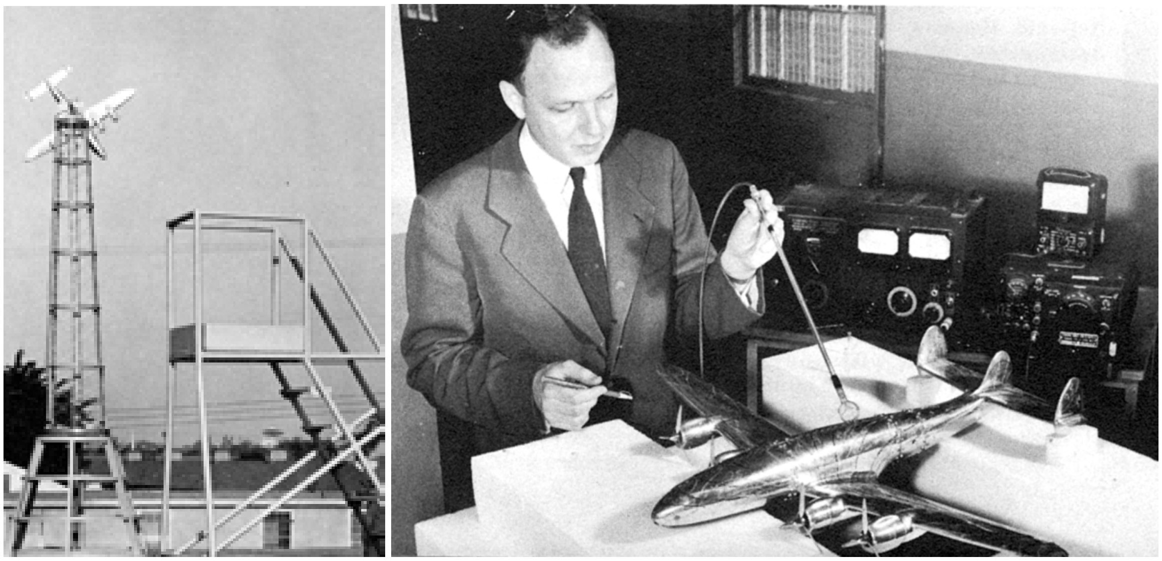

Figure 8-1. Lockheed Constellation on the antenna range and John Granger, Antenna Lab Director, measuring skin currents in the laboratory.

accommodated. As planes began to be built from more plastic and composite, nonmetallic materials, the antenna's electrical isolation from the aircraft skin would also change, often requiring new designs.

One important contribution to radio design at SRI was the introduction of so-called single-sideband (SSB) transmitters to aviation. While SSB in general was not new, a revolutionary design created by Dr. Oswald "Mike" Villard at Stanford University gave higher efficiency and greater simplicity than any earlier method. Created for the U.S. Army starting in 1949, it was one of SRI's earliest projects and the first from its engineering group.[D] Using Villard's later patented approach, SRI's Jack Honey, Don Scheuch, and Oliver Whitby built a 500-W transmitter for the 1.5-30 MHz range, so critical to aircraft in the presatellite era.

SSB was a remarkable improvement in avionics. All other things involving the quality of the signal received being equal, the voltage required at the antenna was but one-third that of conventional amplitude modulation. Thus, SRI was able to increase the efficiency of airborne transmitters and decrease the weight and power requirements in the airplane. The advantages were obvious. For example, the electronic equipment aboard a B-377 Stratocruiser of the day weighed about 800 lb, each pound of which displaced about $5 per year in cargo revenue (about $30,000 per year per plane in today's dollars). Beyond such efficiencies, the new modulation also doubled the number of simultaneous users of the equivalent radio spectrum. This advancement, then, was soon accepted widely in the aviation industry.

National Security Policy and Military Operations

Though not exactly by design, the U.S. defense establishment has been SRI's single most prominent client sector. While much of the funding for that sector goes toward research topics of quite general use, an important component has been in close, direct support of the U.S. national security effort. Here we will briefly discuss just a few of those programs. The first of these programs addresses the nation's civil defense response to the growing Soviet intercontinental ballistic missile (ICBM) threat of the 1950s. Second is SRI's important role in the design of tactical training systems for both air and ground operations. Next, we will relate how SRI contributed close technical and experimental support to the Services, and finally, we will touch on SRI's role in national security policy.

SRI's Role in the Policy and Practice of U.S. Civil Defense Programs[E]

As the number of nuclear weapons of the Soviet Union and the United States increased rapidly during the 1950s, both nations realized that a program of civil defense was an essential part of any national defense program. A United States policy implemented at that time declared nonmilitary defense programs to be an important component of our ability to deter a nuclear attack. This policy stemmed from a recognition that the United States' announced policy of nuclear retaliation in response to major aggression by the Soviet Union would not be very convincing if the United States were not capable of withstanding such an attack. From this reasoning, the U.S. government established a formal Civil Defense program following World War II.

In the early 1950s SRI became engaged in civil defense research for a variety of government agencies. As the nuclear threat from the Soviet Union became more intense and ICBMs entered the equation, SRI was given an increasingly larger role in assisting U.S. government agencies in analyzing and preparing for that threat. Here we recount some of the research SRI conducted to address what might be termed the passive defense measures the United States could reasonably take.

SRI's role in this area ranged widely, from the development of damage assessment systems to the analysis of post-attack problems of survival and recovery. By 1959, SRI had published more than 60 separate reports in civil defense analysis and planning. The following list illustrates some of the tasks that SRI undertook:

- Based on intelligence of Soviet capabilities, analyze the threats to the United States of possible Soviet attacks. Analyses of threats were essential for effective damage assessment and planning efforts.
- Analyze the cost and effectiveness of a variety of shelter programs.
- Study ways to save lives by evacuation from potential target areas or from heavy fallout fields.
- Assess potential post-attack food and water supplies for a survival and recovery period and identify possible problems in production and distribution.
- Analyze the potential damage, recovery, and post-attack capacity over time of the petroleum and fuel industry in the United States.
- Examine the problems and possibilities of predicting the recovery of the medical products industry following a nuclear attack.
- Analyze the damage to transportation systems from a variety of possible nuclear attacks and estimate the post-attack system capability. Between 1959 and 1969 SRI conducted several studies for rail, truck, air, and water transportation systems.
- Study and make recommendation on decontamination and reclamation, facilities restoration, procedures and systems for realistic damage assessment, and command and control issues for operations in a post-attack environment.

These research issues allowed SRI to build up a substantial expertise in U.S. civil defense matters. Its contribution to knowledge in this field led to a meeting held at SRI on May 15, 1959 by the Program Advisory Committee of the Office of Civil Defense and Mobilization (OCDM). The outcome of the meeting was that the government gave SRI a contract to manage a significant portion, at least a third, of the U.S. Civil Defense research budget.

An example of the esteem with which the federal government viewed SRI's civil defense work concerned SRI's manager of Industry and Civil Defense, Rogers Cannell. Following John Kennedy's election in 1960, Cannell was on the "short list" of candidates for appointment as head of OCDM. Although someone else was appointed, the appointee set up an office for Cannell adjacent to his office so that he could use him as a special advisor. Another example was an SRI report by Harvey Dixon and his colleagues suggesting an entirely new approach to analyzing the hazards to people who must operate in an environment of radioactive fallout.[F] Guidelines in existing OCDM manuals for operation in fallout environments were much too conservative in estimating the time that must elapse following a nuclear attack before operations essential to survival and recovery could begin. The quality of Dixon's analysis was such that OCDM completely revised their tables for planning for operations in a fallout environment. A few years later, the National Research Council adopted the same guidelines proposed in the SRI study.

For perhaps two decades SRI made major contributions to the overall civil defense posture of the United States. Research was conducted for three different administrative levels within OCDM and its predecessor agency, the Federal Civil Defense Agency. SRI contributed to the nation's civil defense program by developing research tools and data for government technical staff, conducting systems analyses and operations research for administrators responsible for operations and planning, and helping policy makers develop and tune government policy.

The Development of Modern Air Combat Training Ranges[G]

In the early stages of the Vietnam air war, Navy fighter pilots were experiencing frustration in some of their air combat maneuvers. For example, a squadron operations officer debriefing a Navy fighter pilot upon return from a combat mission might have heard something like this: "Commander, I can't understand it; I'm sure I had that bogey in my sights a long time, yet when I got my shot off, the missile missed wide to the right. I can't figure out what went wrong."

As it turns out, the reason for the miss could have been one of many, including (1) not all of the pilot's cockpit switches were set properly, (2) the pilot was a little inside or outside missile range or slightly outside the maximum aspect angle, (3) the plane was at the wrong attitude, or (4) the missile guidance system failed. Unfortunately, none of these could be known conclusively after the fact. This frustrating ambiguity in the review of actual combat missions prompted the Navy to conduct an "Air-to-Air Systems Capability Review," completed in 1968, that evaluated actual combat operations. The study concluded that there was a critical need to better train Navy pilots in the use of the extremely capable weapons systems that were becoming operational. It also became clear that new concepts were needed to support the air combat training exercises where pilots gained their combat proficiencies. Furthermore, it would be necessary to bring more realism into such exercises so that pilots would come to "train like they fight." Thus, the focus turned to enhancements needed at the Navy's air combat training ranges.

SRI had been advising the Navy for several years on technical improvements to its range instrumentation and so it was natural that SRI would be selected in 1969 to evaluate the available technologies for a brand new in-flight pilot training system. The new system would be revolutionary in that it had to provide a training environment where pilots engage in actual air-to-air combat against other aircraft using all available weapons systems, yet fire no live rounds. The weapon firings and trajectories would be represented by accurate computer simulations, with capability to score results in near real time, and data would be collected to document all the activity so that the entire training mission could be replayed and reviewed from every aspect after the aircrews returned to base. To be sure that SRI fully understood the complexity of the training requirements, SRI project leader John McHenry qualified to fly air-to-air combat training missions in the back seat of an F-4 Phantom, fully participating in actual air-to-air combat exercises and operating the aircraft radar (see Figure 8-2). SRI completed its analyses and recommended a specific technical approach that was adopted. It then developed the system performance specifications, helped the Navy conduct a competitive procurement and select a contractor, and then acted as the Navy's agent in the building and installation of the first system in late 1972 at the Navy's range near Yuma, AZ. The new capability was designated the Air Combat Maneuvering Range, or ACMR.

Shortly after the Navy's first system became operational, the Air Force contracted for several similar systems, which they named Air Combat Maneuvering Instrumentation, or ACMI. Training on these ACMR/I systems proved so successful that they quickly gained acceptance among U.S. fighter pilots as the "gold standard" for realistic air combat training. The total number of ranges continued to grow so that all U.S. fighter pilots (Navy, Air Force, and Marines) not only would be trained on a stateside ACMR/I but would have systems installed overseas to assure that they could maintain their proficiency while deployed. In addition, several of our allies also obtained ACMR/I systems for training their combat aircrews. The SRI design had defined the state of the art. Although actual combat missions were infrequent, pilots who engaged in such missions (e.g., the Libyan incursion in 1981) verified how similar their encounters were to the realistic combat environment now provided in training.

To understand how the ACMR/I systems work, consider that each participating aircraft is equipped with a pod containing range instrumentation including a transponder that is interrogated from a set of ground stations to determine an aircraft's exact situation.

Figure 8-2. SRI's John McHenry entering a Navy F4 (circa 1970).

A transponder probe of the pod reveals the aircraft's position, but the pod also contains gyros and accelerometers to measure aircraft attitude, acceleration, and rates. The newest systems also incorporate a Global Positioning System (GPS) receiver. Because the pod attaches the same way a missile would, it also obtains power, weapon system status, and cockpit switch settings. All of these data are sent to the ground via the system data link for reconstruction in near real time by the ground computers. When the pilot triggers a missile during an exercise, the computer flies a simulated missile at the selected target and calculates, based on the initial firing parameters as well as the maneuvers of the target, whether or not a hit would have occurred. This information is made available in near real time to the pilots in the cockpits and is stored for post-flight reconstruction and display. Scenes in the popular movie "Top Gun" showed fighter pilots flying in these kinds of air combat training exercises and participating in postflight debriefings at the Air Force ACMI in Nevada.

During the first 2 years of operational use, SRI conducted an evaluation of each observed system deficiency, ultimately achieving a ten-fold improvement in system reliability. This scrutiny continued to improve the training utility of each range. At the same time, SRI made incremental design improvements to the range systems by enabling more simultaneously participating aircraft, instrumenting larger areas, achieving greater accuracy, and adapting to new digital avionics systems. Major innovations, such as the ability to include electronic warfare and air-to-ground weapons, were also added. As the training functions of the system grew well beyond air-to-air "dogfight" training, the Navy updated the name of the system to Tactical Air Combat Training System (TACTS).

SRI has also supported new uses of the TACTS/ACMI ranges for research and development applications. For example, range exercises were used to evaluate how much combat advantage could be expected from proposed changes in missile performance by using modified weapons simulations that include the improved performance parameters. Another example was the use of the inertial data collected during training exercises to develop in-flight databases for evaluation of aircraft loading and fatigue. In spite of the fact that SRI was engaged with both the Navy and Air Force in the evolution of each system, they grew separate and distinct through emphases that each Service believed important.

The training also enables the testing of various levels of pilot proficiency. Newly available data varied from continuous feedback to both the attacking and target aircraft to only the kill/no-kill outcome. Also, to reinforce and analyze the experience gained during the live training mission, the TACTS/ACMI systems can replay the entire exercise using high-resolution graphics displays and simultaneous numerical display of important parameters for each aircraft. One of the most useful features of the system is its ability to show the progress of the action from several perspectives, including the view from the cockpit of each airplane involved. With this capability, a pilot can reenact any part of an exercise from his own point of view, or he can see what the action looked like from his target's perspective. This near-real-time, post-flight reconstruction has been a valuable and efficient approach to making American pilots the best in the world. SRI's role in these joint programs has continued for over 30 years, and SRI is now engaged in the next-generation range systems that will have greater accuracy and be able to operate anywhere in the world, independent of fixed ground facilities, by incorporating advanced applications of GPS positioning technology.

GPS Systems and the Training of Armored Ground Forces

One of the most effective innovations for defense systems has been the advent of GPS. Able to provide accurate position information almost anywhere in the world, free from fixed ground facilities, this satellite system has offered new capabilities for both operational and training systems. SRI has contributed significantly to both.

Before relating the SRI contribution to ground force training systems based on precision GPS systems, it is important to understand how SRI got to a point of expertise in that field. Earl Blackwell of SRI had been interested in the use of high-accuracy, differential GPS (DGPS) since the mid-1980s. Such systems use a ground-based reference receiver, whose location becomes precisely known, in conjunction with current satellite transmissions in the proximity of the reference point to compensate for a few of a set of component errors intrinsic to GPS-based systems. The use of DGPS enables sub-meter position accuracy that can provide, for example, the basis for systems such as the automatic landing of aircraft. Under DARPA sponsorship, Blackwell and his SRI colleagues developed in the mid-1990s a DGPS capability for use on precision-guided munitions. The resulting system reduced the navigation component of the overall munitions error to less than 1 m and, in some cases, very much less. Blackwell's team's innovation came in developing a so-called wide-area DGPS approach that used an array of widely spaced reference receivers, thousands of nautical miles apart, to be able to create a virtual reference receiver in the vicinity of the GPS receiver in use.[1] These concepts are now part of a high-precision, all-weather guidance system that does not have to rely on active sensor measurements for guidance in the proximity of the target. Although the SRI wide-area precision technology has been available for years, as of this writing it is just being introduced through Boeing into the Air Force and joint-Services use of GPS-guided munitions.

This ability of DGPS to sense very small changes in the position of a sensor formed the basis for a new and innovative technology for *ground-force* tactical training exercises. As with the Vietnam War instance cited above, Desert Storm illustrated that many of its participating armor units arrived on site with an average of only 39 days of training each year.[H] Some of these were National Guard units whose available training days are clearly limited. They well illustrate the need for a training support system that leaves as much time as possible for actual training maneuvers. Earlier systems for non-fire training maneuvers were based on lasers that required time-consuming calibration and, more importantly, suffered from a lack of visibility through the dust and smoke common to such exercises. Enter SRI and its expertise in DGPS.

SRI's opportunity to bring a new GPS solution to the problem began with a 1994 program at DARPA. It was called Project SIMITAR, and it was intended to provide advanced technology to create realistic, cost-effective ways to build the proficiency of the United States' increasingly called-upon National Guard units. Remarkably, in just 15 months SRI developed an inexpensive, easily deployed instrumentation system called DFIRST™, for Deployable Force-on-Force Instrumented Range System. It was first demonstrated in October 1995 at the Idaho Guard's training area and deployed operationally there the following year. Let's see how it works by stepping into a real, live training situation:

> Over the next two hours, the crew of the 70-ton Abrams tank designated "Charlie 12" will seek out and engage an opposing force hidden amid the rolling hills of the 138,000-acre Orchard Training Area southwest of Boise, Idaho. When an enemy is sighted, the tank turret swings around and the gunner

[1] The conventional separation from a reference receiver for DGPS was less than 300 nm. The SRI wide-area system, with baselines of over a thousand nautical miles, still produced positional errors of less than 1 m. See "A Global DoD-Optimized DGPS for Precision-Strike" by Earl Blackwell, Mark Moeglein, and David Nakayama, presented at the 8th International Technical Meeting of the Institute of Navigation in Palm Springs CA, 12-15 September 1995.

locks onto the target with his 120-mm main gun. The gunner squeezes the trigger. Within milliseconds, processing software in Charlie 12's DFIRST™ instrumentation package verifies that the enemy tank has been correctly targeted and is within range of the gun. An electronic "hit" signal notifies the instrumentation package on the targeted tank that a hit is imminent. The targeted tank's instrumentation package then calculates the virtual damage the "impact" has imposed. When the damage is evaluated as "fatal", the victim tank is stopped in its tracks and all of its weapons systems are disabled. Charlie 12's simulated round was on-target and has given the Blue Force its first success in this battlefield training exercise.

This vignette has a strong resemblance to the air-combat system mentioned above. But in this case the entire DFIRST™ instrumentation suite, including all hardware and software, was not only designed and developed, but also built by project teams at SRI under the leadership of Chris Terndrup. A DFIRST™ unit can be installed on a participant vehicle in less then 30 min. The instrumentation package contains a single-board computer, two GPS receivers, a high-speed radio transceiver and antennas, and a programmable interface controller that connects to the vehicle's electronics system. This interface enables status reports to be broadcast over the vehicle intercom, creates a smoke signature when the gun is fired, and employs a strobe light when the tank has been damaged by enemy fire during an exercise.

The two important measurements for this simulation overlay are the precise location of the vehicle, in this case a tank, and the even more precise knowledge of where its gun is pointing when it is "fired." To learn this latter fact, SRI developed a 1-m-long jig with a GPS antenna attached to each end. The jig can be clamped tightly and accurately to the gun barrel and does not require time-consuming optical boresighting alignment procedures typical of previous laser gun-tracking instrumentation (see Figure 8-3). GPS carrier-phase interferometry software developed by SRI uses the signals received from the two GPS antennas to calculate the gun pointing angles (azimuth and elevation) with an accuracy of less then 0.2 degrees![2] The tank's position is defined using DGPS. Interestingly, the instrumentation package in each vehicle can be made to represent the capability and vulnerability of *any* friendly or enemy equipment. This adds great flexibility to the scenarios the exercises can portray. Even more flexibility and threat types come from simulated or virtual artillery batteries and minefields, the existence of which are briefed up front and which can be "exercised" during a maneuver. As of late 2002, the ability to integrate live and virtual or simulated conditions regarding enemy orientation and actions was being installed for the California National Guard. There, through computer networking, a command post in south Los Angeles can send orders to a tank unit at Camp Roberts near Paso Robles, while another Guard Unit in San Luis Obispo dispatches simulated soldiers to a virtual, interactive battlefield that is shared by all participants! With these options and the freedom to maneuver anywhere, the composite experience becomes realistic indeed.

As in the case of the TACTS/ACMI air combat range systems, all the firing, positioning, and communications events in the practice exercise are recorded for detailed review after the fact. A trailer, designed as an exercise control center, is also the setting for the visual depiction and study of each completed exercise.

As a final comment on the resilience of the SRI system and it designers, the Guard decided they wanted to use live rounds in some instances. The GPS jig on the barrel was modified so that just its computing module was hid behind the turret to protect it from the recoil and blast. DFIRST™ chief engineer Gerald "Jerry" Lucha and other SRI staff did this all in the field, and at the same time gave the exercise safety officers the ability to monitor gun-pointing directions to ensure that rounds would land in safe areas. The "live fire" modification was later incorporated into the design.

Since the initial DFIRST™ deployment, another half dozen systems are on tap for use at other Guard locations around the United States,

[2] While this accuracy from GPS is good, it is only good enough to indicate which target is struck and not how badly the target is damaged. For that, the exercise support system rolls the dice and indicates to the target its degree of incapacity. Also, the algorithm computing the ballistic trajectory of the shell does not yet allow for intervening terrain. In other words, no digital terrain map is involved, as there eventually should be.

Figure 8-3. SRI's attitude-measuring jig mounted on the barrel of an Abrams tank.

and it has become a standard ground instrumentation system for a series of annual joint-Services exercises conducted to evaluate tactical combat identification systems and procedures. Thus, this system, together with TACTS/ACMI, helps explain why the U.S. forces are the best trained in the world.

Close Support in the Doctrine and Technology Enabling New Military Operations[3]

While it is true that separate, individual projects made up most of SRI's work for the DoD, there were important efforts that began instead with an organizational relationship. Somewhat resembling the RAND Corporation or other institutions such as MIT and Johns Hopkins, SRI had a few instances when, at the request of a particular military service, it established an organization whose functions were closer to continuous broad technical support. This work tended to deal mostly with the introduction or evaluation of new technology or systems. Two such SRI groups were prominent: the Combat Development Experimentation Center (CDEC), which ran from 1958 to 1966 for the Army's Combat Development Command, and the Naval Warfare Research Center (NWRC), which began in 1957 under the aegis of the Chief of Naval Operations and later shifted to the joint purview of the Office of Naval Operations and the Marine Corps.

Combat Development Experimentation Center (CDEC)

In the spring of 1958, Brig. General Fred Gibb landed his helicopter in the SRI parking lot for a meeting with SRI's president, E. Finley Carter. The Army wanted SRI's help, and Gibb's message was that it was SRI's "patriotic duty" to submit a sole-source proposal to the existing CDEC unit at Fort Ord, CA. It was an opportunity that SRI had earlier decided to pass up. After Gibb left and a few internal meetings had taken place, Tom Morrin, director of Engineering at SRI, decided to submit a proposal for nearly $1 million. To everyone's surprise the Army accepted it, and Dr. Manning Hermes became the first on-site director.

CDEC, as the name implies, was intended to explore new concepts and doctrine for the field Army through mainly observational and analytical means. New ideas were considered and discussed, then tried in the field in an attempt to learn their efficacy, often through direct, quantitative measurements. The topics addressed came mostly from the Army and this was definitely hands-on work. While the group itself was located at Ft. Ord near Monterey, CA, the "laboratory" for most of the fieldwork was located at the vast Camps of Hunter-Liggett and

[3] This section and the one following on SRI's Strategic Studies Center were prepared with input from Larry Low, Lloyd Peters, and Maury Deatrich.

Roberts located farther south.[4] To carry out this mission, CDEC was assigned 3000 officers and men and a full complement of military equipment.

The CDEC's investigations were eminently practical. The first was to explore the vulnerability that ground fire presented to slow, low-flying aircraft and helicopters. In this project, fiberglass helicopter mockups were towed over "hostile" terrain, where they were shot at by various types of ground fire. Actual quantitative damage assessments were then made. The SRI analysis, when presented to the Commander of the Army Aviation School in the spring of 1965, led to a redesign of such tactical aircraft maneuvers. Another recommendation, relating to a new, more mobile Army, precipitated the procurement and integration of armored personnel carriers at the normal infantry company level. Many other experiments were run, including ones that addressed the basic individual arms carried by the soldier and a large one concerning the design of the Army's so-called Forward Area Air Defense system. The latter addressed the topography of Germany, where wargaming was carried out in anticipation of a breach of the border by Soviet troops and armament. SRI's involvement in CDEC continued for 8 years, ending in September 1966. As one might expect, not all concepts that were explored, like the five-platoon infantry company, were successful, and many of those that were, never saw implementation.

The Naval Warfare Research Center (NWRC)

As with most of SRI's dealings with the DoD, the origins of NWRC were rooted in exploring the potential roles of new technologies, in this case for future Navy operations. Because of Dr. Fred Terman at Stanford and Tom Morrin at SRI, the Navy hierarchy thought of the Stanford community as they pondered their need for another outside research center where analysts, unencumbered by day-to-day operational turmoil, could reason about longer-term (10-15 years) developments. Because of this longer-term perspective, NWRC became aligned with the Office of Naval Research and, somewhat because of an existing void in the Navy's consideration of amphibious operations, the Headquarters of the Marine Corps.[5] The NWRC enlisted specialists not only from SRI but also from Stanford, other universities, and industry.[6] An advisory committee consisted of senior officers and civilians of the Navy, the director of SRI, and Stanford's provost, Fred Terman. It began operation in 1957 under the direction of Harry Bridgeman and ran until the summer of 1979.[7]

By 1962, the Navy would narrow NWRC's mission to examining new technologies and systems that could enhance naval tactical warfare, again in the long term. With such evaluations there came the attendant need to develop better analytical models and evaluation methods with which to determine whether such changes, in fact, constituted progress. Of the many concepts explored by NWRC, and there were more than 250, only a few of the most important ones will be mentioned here.

Fleet Air Defense. The development of advanced air- and ship-borne radar systems opened the way for a more comprehensive approach to the air defense of an entire carrier task force or battle group. Under the initiative of Larry Low, later to lead the NWRC for over a decade, and Fred Forsyth, SRI analysts created over a period of 8 years a method to determine the effectiveness of a carrier-group air-defense system. Its evaluation included the individual contributions of components like early warning and shipborne radars, air-to-air and surface-to-air guided missile systems, electronic countermeasure systems, and the command and control systems that managed all of them.

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[4] The early SRI CDEC team included Manning Hermes, who led the overall project; Frank Harris, who led military plans and programs; Phil Sorensen, who led operations; Vincent Fend, who led data analysis; and Henry Alberts, who led instrumentation. Maury Deatrick was the project scientist. Oversight responsibility was first given to an SRI committee and then to Gordon Wiley.

[5] Placing such a *research* center away from the bustle and demands of the Washington, D.C., area was initially considered a virtue; hence a location on the West Coast such as SRI. Still, it did compete with very long-standing institutions such as the Navy's own Naval Studies Center at the Naval War College and the Federally Funded Research and Development Center located in the D.C. area called the Center for Naval Analyses, begun in 1942. The proximity of this latter organization to Navy headquarters lent itself to the rapid turnaround and "short string" control characteristic of *operational* support groups. The inherent competition between the three centers initially led to a partitioning of work that left the NWRC aligned only with the Office of Naval Research in the role of exploring the long-term operational impact of new technologies. NWRC's role with the Marine Corps remained more general.

[6] The NWRC was started somewhat at the expense of an aging relationship the Navy had with MIT.

[7] Subsequent directors were: A.E.D. Rist, Larry Low, and Al Bien.

This model provided the technical underpinnings for the performance specifications and design of the Aegis Weapon System and became an ongoing analytical tool at the Naval Research Laboratory.

Integrated Command and Control. In the early 1960s, the increasingly complex tactics enabled by rapid maneuvering and advanced weaponry called into question the type of command and control (C2) systems needed for Marine amphibious operations. Would a more integrated control system better match the dynamic nature of the coming amphibious battlefield? The HQ of the Marine Corps asked NWRC to examine this problem, and for the first time amphibious warfare was scrutinized for the needed information flows offered by a rapid, technology-driven C2 system. Lloyd Peters and other analysts identified the areas of information shortfall, and a new organization was established in the Marine Corps to learn the benefits of displays, decision aids, and advanced C2 concepts.[8] New concepts in amphibious operations continued to be studied at NWRC, including the configuration of the force itself. Examples were the role helicopters and advanced air-cushion landing craft could play in conventional and over-the-horizon assaults. Such evaluations led to the ships and landing craft in today's inventory.

Introduction of Computers into Tactical Units. In alignment with the above innovations in an advanced and integrated C2 system came the diffusion of computers into lower levels of the Marine Corps. Previously the province of the higher administrative levels of the Service, computers were seen as a necessary part of driving the slow paper accountability and reconciliation practices out of low unit operations. NWRC examined the question of small, rugged computers down to company level and defined their required capabilities. Although this was all prior to the existence of "personal" computers, machines were specified and procured that come to last three times their planned 5-year lifetime. Now, many years later, computers are serving individual Marines for important leverage in tactical, not just administrative, operations.[9]

Marine Corps Aviation Requirements. When it was posited that Navy and Air Force air support was adequate for Marine operations, NWRC was asked to examine the assumptions on which the assertion was based. Requirements were painstakingly derived based on need and the most cost-effective solution. The results supported the acquisition of the vertical/short takeoff and landing (VSTOL) Harrier aircraft for offensive air support of ground troops.

Many other impacts flowed out of NWRC, including the design of acoustical decoys and maskers for anti-submarine protection, mass spectrometers for submarine detection and identification using chemical analysis of their wakes, the reliance on satellites for navigation and communications, meteorological lidar for weather and airborne particulates, and general force requirement models for military planning. For over two decades, many NWRC people such as those mentioned, plus air defense specialist Fred Forsyth, airborne sensor expert Jack Willet, logistician Bert Wilder, and the other directors, Dave Rist and Al Bien, pursued such insights by making use of SRI's broad technology base. NWRC's conclusion at SRI came from one of the seemingly cyclical decisions in the military, in this case Navy HQs, to forgo the need for exploring the role of long-term technology in its operations.

The SRI Strategic Studies Center[10]

The SSC was somewhat different from the two Centers just mentioned in that its establishment did not arise out of the unsolicited actions of the military. Unlike the CDEC and NWRC, it was not, as an organizational entity, a line item in a military budget. The SSC was created more in the tradition of other SRI research groups; that is, largely through the efforts of an entrepreneur who wanted to do significant work in a selected area. In this case, the entrepreneur was Richard B. Foster.

Perhaps the most important trait of the SSC over its 30 years of existence was its repeated ability to gain early insights into important national security threats and then to convey these insights to increasingly higher levels of our military and the executive branch. One of

[8] That organization, the Marine Corps Tactical Data Systems Support Activity housed at Camp Pendleton, still operates in that capacity today.

[9] See Chapter 3 for SRI's role in the introduction of small, handheld computers into small-unit Marine operations.

[10] Insights into this Center and its operations came from Larry Low, George Hagn, and most importantly from those who were personally involved: Bill Carpenter, Leon Sloss, William Lee, Cathy Ailes, Charles Movit, Penny Foster, Herb Levine, and Harriet Fast Scott.

the paths that Foster would take was defined in the mid-1950s, when the SSC first examined the U.S. air defense systems for the U.S. Army.[11] A second path began with an important 1959-1962 examination of communications in support of military commanders that came to focus on command at the highest operational level, the so-called national command structure.[I] That period was a time of transition and consolidation, both in how the military was organized to fight and because of the centralization of certain DoD functions such as communications and logistics.[12] A third path was the opening of an extended dialog between U.S. and Soviet researchers during the midst of the Cold War.

Sponsored from within the Army Signal Corps, the examination of high-level U.S. communications was a landmark study. It was one of the earliest expositions on the unification required of what had been two separate functions, communications and command. As a case in point, the final report began with one of the first definitions ever of command, control and communications (C3), a term and concept that is now firmly entrenched in the military vernacular of all Services.[13] The study also gravitated early toward consideration of C3 at the highest or JCS/presidential level and showed that at that level, in spite of ongoing centralization, communications assets were still fractionalized. This perspective would carry forward to later SRI critiques of national security such as whether, under attack, the United States could assure the continuity of its government.

Along the other SSC defense systems path, the threat was migrating beyond airplanes to ballistic missiles. The Center's critical examination of the limitations and vulnerabilities of our major defensive systems became of utmost importance to our assessment of national survival. In 1963 the SSC was one of the first groups to use Soviet intelligence material to gauge the vulnerability of our defensive systems to ICBM attack, be they early warning air-defense radars (SAGE) or our retaliatory Strategic Air Command. Also, because of the reliance of these systems and other critical systems on our own communications infrastructure, it too regained a focus for concern. SSC reports on all of these risks were briefed widely in the national security establishment, including the Secretary of Defense (McNamara), the JCS, the Secretaries of the three Services, the Air Force Chief of Staff (LeMay), the intelligence community, and, in 1968, President Nixon himself. Similar vulnerability studies were done for groups such as the National Security Council (NSC), the Federal Emergency Management Agency (FEMA), the Central Intelligence Agency (CIA), and a range of military groups, as well as ongoing work for the Army. Along the course of these studies in the 1960s, one concept that now seems perfectly logical emerged from the SSC. Rather than taking a piecemeal approach to the various threats or concentrating just on the Cold War, Foster advocated that the United States prepare for what he called a "spectrum of conflict," one that ranged continuously from terrorism to all-out nuclear war.

Also in the 1960s came the next step in the escalation of national defense systems, the feasibility of a U.S. anti-ballistic missile (ABM) system. The SSC had been studying the various ABM approaches from the 40-city defense and Nike X, to the Sentinel system, to the point defense of silos with Safeguard. Along the way Foster, using SSC studies, had convinced McNamara that an ABM system was, in fact, cost effective compared with what the Soviets would have to lay out to defeat it.[J] But McNamara had also come to believe in the philosophy of mutual assured destruction and therefore saw an ABM system as destabilizing. So, while the whole ABM notion continued to be explored, nothing was ever deployed. But there was one other episode of the time worth mentioning.

According to Foster's own account, he and SRI's head of Engineering, Ray Leadabrand, hosted a meeting at SRI in about 1964 to air the pros and cons of various ABM approaches.[K] Attending were distinguished strategists such as

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[11] For this work Foster received a citation from the Department of the Army.

[12] The revamping of the DoD's reporting structure for military operations involved the establishment of the so-called unified and specified commands, reporting directly to the Joint Chiefs of Staff, in 1958. The Defense Communications Agency was formed in 1960 and the Defense Supply (later Logistics) Agency in 1961.

[13] "A Retrospective Look at Some of the Basic Issues Connected with National Command, Control, and Communications," an unclassified reprint of a 1962 final report on the Signal Corps project. This report was a very early exposition, if not the first, of the need to closely associate the ability to command in a rapidly moving world with the only means for doing so, electronic communications. The *command* responsibility to *control* assigned forces through adequate *communications* (C3) has since been, and will continue to be, a single, integrated function.

Herman Kahn and Albert Wohlstatter, the nuclear physicist Edward Teller, and a host of other respected scientists and economists. The meeting was intended to debate the issues surrounding ABM systems from either a purely defensive posture or including offensive measures. As the story goes, Teller came to the meeting uncommitted, not having thought much about the growing ABM controversy, but left with the notion that an ABM system might be both technically and economically feasible. While another 15 years or so would pass as Teller solidified his pro-ABM views, he became the one most influential in convincing Reagan that a *space-based* ABM system made sense. His ABM orientation, of which the SRI meeting may have been but the opener, was eventually important to the U.S. entry into the era of the Strategic Defense Initiative (SDI), or "Star Wars." Rounding out the threat, Foster himself also later briefed Reagan and the NSC on the possibility of other nations, such as China, North Korea, and Iran, obtaining their own ballistic missile capability. Such studies and interactions brought the SSC into the area of disarmament discussions, and a former SSC member, Ken Adelman, became Director of the U.S. Arms Control and Disarmament Agency under Reagan from 1983 to 1987.

But this propensity toward high-level interaction brought both opportunities and controversy. It was perhaps the nature of presidential- and JCS-level Cold War decision-making that it was almost always immersed in contention. Because of this and Foster's own tireless, assertive personality, controversy seemed to accompany the SSC. Although much of its commentary was insightful and comprehensive, it was, of course, not always prescient or accurate. The technical adequacy and affordability of SDI and its subsequent alternatives continue to be problematical against realistic threats. Further, because such systems violate the 1972 ABM Treaty with the Soviet Union, they introduce at least some instability to long-term disarmament. On the other hand, the escalation such new ABM systems represent may have, in part, contributed to the realization by President Gorbachev that any race involving "tit-for-tat" systems was economically infeasible for the Soviet Union if its other domestic needs were to be addressed.[14] It would be hard to overestimate the importance of that realization. In another case, the SSC took the position that, because of the dependence of national security on our communications infrastructure, Congress should have promoted legislation to negate Judge Green's 1984 decision, following which American Telephone and Telegraph (AT&T) agreed to dissolution. While it is not clear that such an initiative would have materially benefited national security, it was clear that AT&T's regulated monopoly had become totally unrealistic in a worldwide wave of deregulation.

The last SSC item to be covered here is Dick Foster's initiative in bringing U.S. researchers and Soviet academicians together in the politically stressful 1970s. It started somewhat by accident when a Soviet member of IMEMO (Institute for World Economy and International Relations), V.M. Kulish, was on a month-long visit to the State Department in late 1969. In an attempt to help keep him busy, the State Department asked Foster if he would host Kulish for a day. When a member of the SSC, Harriet Fast Scott, recognized this name as a former ranking military officer, Foster perked up and used the opportunity to get invited to Moscow. Later this relationship would help develop a series of meetings between U.S. and Soviet researchers and strategists. Over the next year or so, as Scott accompanied her husband, who became a military attaché in Moscow, she

[14] The popular, but almost certainly incomplete, story was that it was Star Wars that brought Gorbachev to the hopeless realization that, given his faltering economy, the USSR could not maintain military parity. But, it was true that he was committed to a continuing reduction in military spending so as to help domestic revitalization. These Soviet economic realities in the face of Reagan's escalation of military technology, plus Gorbachev's unwillingness to contain the nationalism resurfacing within the Union, and possibly even their mutual desire to avoid a nuclear conflagration, may have each contributed to its eventual breakup. While there have been informal assertions that the SSC had, in fact, predicted the Soviet economic collapse, I have found but one tenuous thread. The SSC spent a great deal of effort examining the cloaked and confusing methods the Soviet centralized planning system used to allocate military and other spending. The difficulty in understanding this process led to some disagreements within the SRI Center. But the evidence arose there that the Soviets were spending perhaps twice as much on their military programs as the CIA had long been reporting to the President, about 16 versus 8 percent of their GNP in the mid-1970s. William Lee was the analyst who shed this light, and his estimates were eventually accepted by the U.S. Government. These data, along with the economic and social implications of Soviet overspending on its military, were eventually published in his book with Richard Starr: *Soviet Military Policy – Since World War II*, Hoover Institution Press, Stanford University, 1986.

helped Foster, with Kulish, set up such an exchange.[15]

The annual meetings began in WDC and alternated between there and Moscow for a number of years. Although one might expect that these had some State Department sponsorship or sanction, they were apparently drawn only from the fertile mind of Dick Foster. This meant that SRI probably footed a good bit of the cost. The meetings clearly involved influential people, mostly researchers from the U.S. side and a variety of academicians and incipient political leaders from the USSR.[16] The discussions were centered on formal papers, of which each side received advance copies. The topics involved economics, political affairs, and military strategy. (The SSC found out later that, in spite of its name, about half of IMEMO was military.) One of the most important people, and the host of the second meeting in Moscow, was Yevgeny Primakov, then IMEMO's deputy director (see Figure 8-4). He later would become its director and eventually Russia's Prime Minister under Yeltsin. He and Georgy Arbatov, head of the U.S. and Canada Studies Institute, the other Soviet organization to participate, would make sure that the meetings followed an acceptable line of discussion.

Figure 8-4. Russian host Yevgeny Primakov and SRI Pres. William Miller. Primakov would later become Prime Minister (courtesy of Wm. Miller).

The consequences of the gatherings were a bit ethereal. Much later, after all this was over and each was a private citizen, Kulish told Scott in Moscow that she had no idea how much the meetings helped the Russian moderates in IMEMO influence the Soviet government. On the other side, SSC members and other attendees would brief various parties around WDC, including the Pentagon, on each meeting. All along there was the tacit assumption that everyone was in an intelligence-gathering mode, they perhaps more formally than us. However, much of that was of the academic kind. Herb Levine of the Wharton School and an attendee at the second conference in Moscow said they helped in the refinement of the best macroeconometric model of the USSR, which was published by the University of Pennsylvania in 1977.

[15] Within the SSC there were dissenting views, such as those of Ken Jacobson, on Kulish and the value of subsequent interactions with the Soviet research and economic community. (Email dated June 4, 2002)

[16] As an example, some economists were: Gregory Grossman (UC Berkeley), Larry Klein and Herb Levine (U. Pennsylvania), R.W. Campbell (U. Indiana), Edward Everett (Brookings), Abel G. Aganbegyan (later the principal economic advisor to the Soviet Government and head of economics at the Russian Academy of Sciences) and Alexsandr Petrikov (noted agricultural economist). Klein later won a Nobel Prize, and Everett became an economic advisor to George H.W. Bush. Sovietologists such as Marshall Shulman (Columbia), Richard Pipes (Harvard), and Thomas Wolfe (RAND) attended, along with Soviet strategists like A.A. Kokoshin (who would become Yeltsin's Security Council chairman and later first Deputy Defense Minister).

One humorous but sobering incident occurred at the first meeting in Moscow. Two economists, Herb Levine of the Wharton School and Ed Everett of the Brookings Institute, were invited to visit Gosplan by its director, Nikolay Baybakov. Gosplan was the principal planning organization for the Soviet centralized economy. During a tour they were talking with an agricultural economist, and he was mentioning some of the possible benefits of a free market economy in motivating Soviet farmers. Director Baybakov interrupted him and, with some belaboring, cautioned that it would nevertheless still be important to control the ratio of cabbages to lettuce! According to Levine, the reaction of the U.S. visitors was not so much humorous as disheartening.

Airplane Electrostatic Dischargers

You are in a modern jetliner and seated at a window having a good view of the plane's wing. Out near the tip of the wing you notice several, pencil-size elements attached to the wing's trailing edge. They are called electrostatic dischargers, and most of the ones you will see are of a type invented at SRI.[L] Their role in the plane's operation is to quiet the radio noise in the aircraft's receivers so the pilot can engage in reliable communications. Invented in the late-1950s, today they are used on all commercial jets and on many military and general aviation planes as well.

As an airplane passes through the air, it builds up electric charge on both its metal and dielectric surfaces. This buildup continues to increase until a breakdown or discharge occurs between the dielectric surface (e.g., canopy) and adjacent metal surfaces and from the metal surfaces into the surrounding air. These rather random electrical discharges create, through the plane's antennas, static in the airplane's radios. This static, called precipitation static, makes the radios difficult to use. Such interference caused the loss of planes in World War II.[M] The sources of the charge buildup include particles in the normal air, such as dust and precipitation. In addition to this charge accumulation, ions are also released in the engine exhaust, so that the engines also become charged. Third, charge can sometimes come from gradients in the Earth's electrostatic field. All these sources are unavoidable—so what can be done to mitigate their effects?

The buildup of charge was known and of interest during WWI, when the presence of hydrogen in some dirigibles made electrostatic discharges dangerous. The Naval Research Laboratory invented some carbon-impregnated dischargers in the 1940s, but they did not consider the directional fields associated with the static breakdown.[17] Beginning with the basics, SRI began its investigation into the causes of precipitation static in about 1954. This start was in conjunction with the design of the conformal antennas mentioned earlier. A few years later, and under a basic ordering agreement with the Air Force Cambridge Research Labs, came an invitation to specifically examine the noise associated with aircraft communications. As planes were flying faster, the buildup of charge on the wing increased, as did the size of the discharge. Although the source became a clearly accepted fact, the question was how to discharge the wing more continuously and thus create a smaller impact.

The answer, developed by Drs. Robert Tanner,[18] Joe Nanevicz, Richard Hilbers, and others in SRI's Electromagnetic Techniques Laboratory, embraced a couple of important concepts. First, the voltage at which the breakdown occurred could be reduced so that the magnitude of the discharge would be smaller even if more frequent, and second, electromagnetic theory suggested that orienting the discharge perpendicular to the plane's antenna system would reduce the cross-coupling even further. The magnitude of the breakdown was reduced by forming an extremely small point on a conducting device attached to the trailing edge of the wing. This point, significantly finer than a sewing needle, provided a low impedance path for the charge to leave the wing's surface. The second part of

[17] Private communications from Kevin Hendricks on 8 Aug 2002. Hendricks is a staff member of Dayton-Granger, Inc. the company that now makes dischargers including the SRI type. They purchased Granger Associates in 1975, which had in turn licensed the technology from SRI in 1963. Dayton-Granger sells dischargers to the commercial aviation industry, the military, and the general aviation community.

[18] Some of the discharger design stemmed from Tanner's Stanford PhD thesis.

Figure 8-5. Some of the first SRI precipitation-static dischargers, their wing mounting location, and SRI's Dr. Joe Nanevicz.

the solution was geometric, having to do simply with the relative orientation of the discharge pins and the plane's antennas. Many prototypes were made, and some were taken in the late 1950s to the Boeing plant in Seattle to test on their 707 jetliner (see Figure 8-5). Refinement resulted in discharge devices that reduced the interference by a factor of 100,000, and SRI received a patent on the process.[19]

The functional part of the pencil-size device lies at its trailing point, where the electrical charges leave the plane. As mentioned, one of the design parameters that ensures a good flow is the sharpness of the end points. However, getting a fine enough point on the end of the dischargers called for a bit of practical ingenuity. A technician on the project, John Papacosta, realized that repeated dipping of the end of the conductor in an acid bath would etch the tip to a taper sharper that any machining could do. To give long life and avoid etching and pitting of the sharp point when in use, the tip was built of tungsten. Some of the prototype configurations are shown in Fig. 8-6.

The resulting devices were called precipitation-static dischargers and have become a standard part of aircraft operation maintenance. Because the Air Force sponsored this work, they had the first right of refusal in its commercialization.[20] After considering it, they decided they were not interested and surrendered the rights to SRI. SRI in turn assigned the patent rights to Bob Tanner, who wanted to leave SRI and pursue the commercialization of the dischargers.

The time was July 1956 and the leader of the laboratory, Dr. John Granger, was also deciding to leave SRI with colleague Jack Bolljahn to start a new company. Seeing the electrostatic precipitator as an attractive product,[21] Granger purchased the patent from Tanner in an arrangement that involved some money and royalties. Tanner, Nanevicz, and others were also considering joining the new company, to be called Granger Associates, when Bolljahn suddenly died. At this turn of events, Tanner left SRI to form a West Coast operation for another company called TRG, and Nanevicz remained at SRI. Granger Associates began manufacturing the dischargers for the airline industry and did so for almost two decades. In 1975 Granger sold the product line to Dayton Aircraft Products that now sells the dischargers under the name of Dayton-Granger Inc. Although the precipitator has had a long and successful history as a commercial product, only the manufacturers and Bob Tanner, not SRI, received any compensation.

After this work had run its course, the Air Force Avionics Laboratory asked SRI to examine similar precipitation static effects on very high performance supersonic aircraft that were emerging. In a very practical approach, SRI built a refrigerated chamber into which ice fog and other particles could be inserted. Bullets were then fired into the chamber at the appropriate speed and the resulting charge induced in them was measured. It was observed that solid ice

[19] The patent was issued to the U.S. Air Force, who must have subsequently assigned the rights to either SRI and/or the inventors: Apparatus for Measuring RF Noise by Passive Electrostatic Dischargers for Aircraft, Patent 3,387,215, dated 4 June 1968 (filed July 1965). Inventors were Robert Tanner, Joseph Nanevicz, G. Richard Hilbers, and Edward Vance.

[20] Curiously, the Air Force did not then continue to pursue the use of precipitators on its own aircraft. They later came into use, however, and today are found on aircraft like the C130, the C141, the F111, the F16, and no doubt others. Dayton-Granger even sells them to Russia for the AN-225!

[21] The fine-tipped precipitators would eventually wear out due to ablation, meaning there would be an ongoing need for replacement.

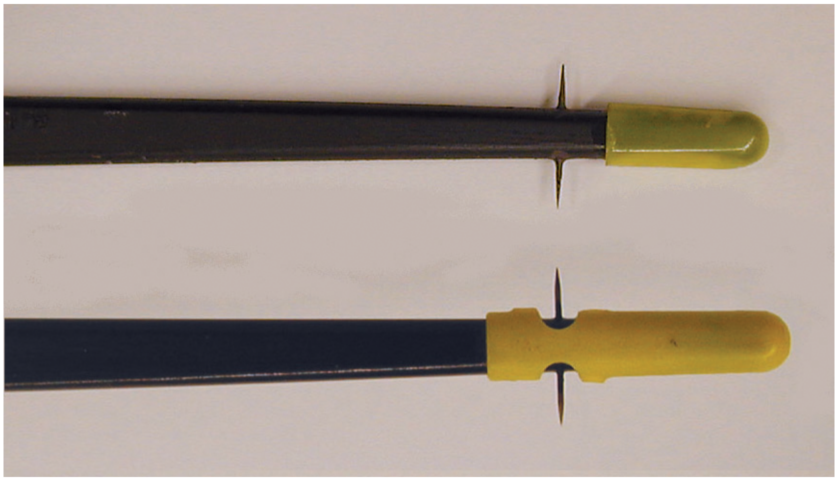


Figure 8-6. Prototype electrostatic dischargers built at SRI.

particles, one of the important producers of charge buildup in subsonic aircraft, continued to increase charge with speed, but at speeds approaching Mach 3 the ice actually began to melt on impact, leaving water droplets, which have a much reduced charging ability. In other words, the results didn't indicate that a separate solution for supersonic speeds was needed.

Matters of Stealth

Dr. Oswald G. Villard (Figure 8-7) had a distinguished career of technical achievement. Known throughout the radioscience community as "Mike," he was a professor at Stanford for most of his life, held many awards, and was a long-term, high-level advisor to the Navy, the Air Force, and other government agencies. Villard also had a relationship with SRI almost from its inception. The first interaction came in 1948 when he chose to explore cooperatively with SRI a new idea he had for the power-efficient (single-sideband) modulation mentioned earlier.[N] A second collaboration came when SRI and Stanford University co-developed and built the radioscience facilities on the hills behind the Stanford campus, when Villard was director of the Radioscience Laboratory at Stanford. The third interaction happened after a couple of Stanford Labs were relocated to SRI in 1969 after the student uprisings concerning the Vietnam War. This last affiliation became the most complete and most notable, for though retaining a few responsibilities at the University, Villard joined SRI and remained on its staff until his retirement in 1996.

Of all the projects that Mike Villard contributed to at SRI—and there were many—none were to have as much impact as those dealing with the general subject of controlling the returns of radar and sonar signals, an area now widely known as "stealth." In particular, his contributions involved "active stealth," called that because it required real-time measurement of the incoming enemy radar or sonar signal and a related retransmission back toward the radar from the object being illuminated. Here we will recount his early exploration of stealth at SRI, both in the electromagnetic and acoustic realms. Both resulted in a very long series of excellent scientific investigations at SRI and correspondingly long periods of sponsored R&D. Both had a significant impact on SRI and the U.S. military posture. Let's look first at the radar or electromagnetic side.

Active Electromagnetic Stealth—Radar Signature Control

In the electromagnetic realm, there are three ways to diminish the returned signal that a

Figure 8-7. Dr. Oswald G. "Mike" Villard

radar uses for detection. One is to absorb the incoming and outgoing (reflected) wave so that it falls below the threshold of the radar receiver. The second is to deflect or scatter the signal in directions other than toward the receiving radar. The third is to radiate a signal in the direction of the radar that adequately represents the composite reflection from the target in the radar's direction, but is of opposite phase to the normal reflection. This results in sufficient cancellation of the total radar return to draw it below the radar's threshold. This last technique is called active cross-section control, and one of its earliest realizations took place at SRI in the early 1970s. In fact, at the time of the SRI investigations, the term "stealth" was not yet coined for this technique. These first experiments were truly "proof of principle" and were conducted in the same manner as all of the work Villard and his team performed: doing fundamental work, keeping good records, and either publishing the results or taking them to research sponsors to get the resources to develop them further.[22]

Active stealth was associated mainly with low-frequency radars where the wavelength was of the order of the plane's largest dimensions. In the mid- to late 1960s, these radars were being developed for the long-range detection of airplanes, often beyond the horizon. These two facts dictated the use of frequencies of the order of 10 MHz so Villard began his investigations at about 8 MHz. The question was simply put: Could an airplane that was being illuminated by a low-frequency radar transmit a signal back in the direction from which the radar signal came that would cancel the one being reflected by the skin of the airplane? Being able to do this required some knowledge of how the airplane appeared as a reflective source from all the angles from which it might be illuminated—a complex concept that could prove difficult to solve. As it turned out, understanding the concept was manageable, but let's turn to the experiments that confirmed its utility.

The setting was the Palo Alto airport, a small community airport serving the civil aviation needs of the local communities. As just mentioned, testing the concept of active radar signal cancellation required a radar, a way to detect the radar and its direction of arrival in the target plane, and a means to generate there a canceling signal in the exact reverse direction. Figure 8-8 shows the makeshift setup at the Palo Alto airport on May 23, 1972. On the table is a laboratory "radar" with its corresponding antenna some distance away. First, the airplane's polar radiation pattern, that directional scattering of signal when the plane is illuminated from various directions, was examined while the plane was on the ground. Over the range of frequencies of interest, the pattern was well behaved, at least as compared to microwave frequencies. Its pattern was not unlike that of a simple half-wave dipole. If so, then, the placement at the center of this dipole of a signal of equal and opposite phase would reduce the reradiated signal, including in the direction from whence illumination came.

This concept was tried first in the laboratory and then repeated in the air aboard a rented AeroCommander 500. Flying in the distance, the plane was equipped with a dipole stretched along its wings, and inside, the secret weapon: a well-informed, highly dexterous SRI team member, Jim Lomasney. His job, amid no small amount of turbulence, was to gauge the characteristics of the incoming radar signal and then adjust the characteristics of the one to be radiated so as to just cancel the current at the center of the dipole. This meant he was simultaneously juggling both the amplitude and phase of the outgoing signal. Switching this signal on and off gave clear evidence at the radar receiver that the returned signal could be made to disappear. Villard, Wanner, Lomasney, and the others had clearly shown that active cancellation worked…at least at these low frequencies!

All of this exploration was done on SRI's own internal research money. With these results they were able to get DARPA funding and, with the additional involvement of SRI's Phil Fialer, Larry Sweeney, and others, SRI refined the approach even further and applied it to other, larger airplanes. The time frame was 1973-4.

Within a year or so, and after the technique was refined, they took their system to Florida where a high-frequency (3-30 MHz) surface wave (low angle) radar was being developed and tested. The SRI technique worked so well that the first look the radar operators got of the airplane was when it was directly overhead. Ralph Wanner remembered that SRI's

[22] The SRI radar cross-section reduction team consisted of Villard, Jim Lomasney, Clair Powell, Ken Johansen, Robert Lloyd, and the person from whom came much of this account, Ralph Wanner. Ernest Aho would help in the acoustic wave analog to follow.

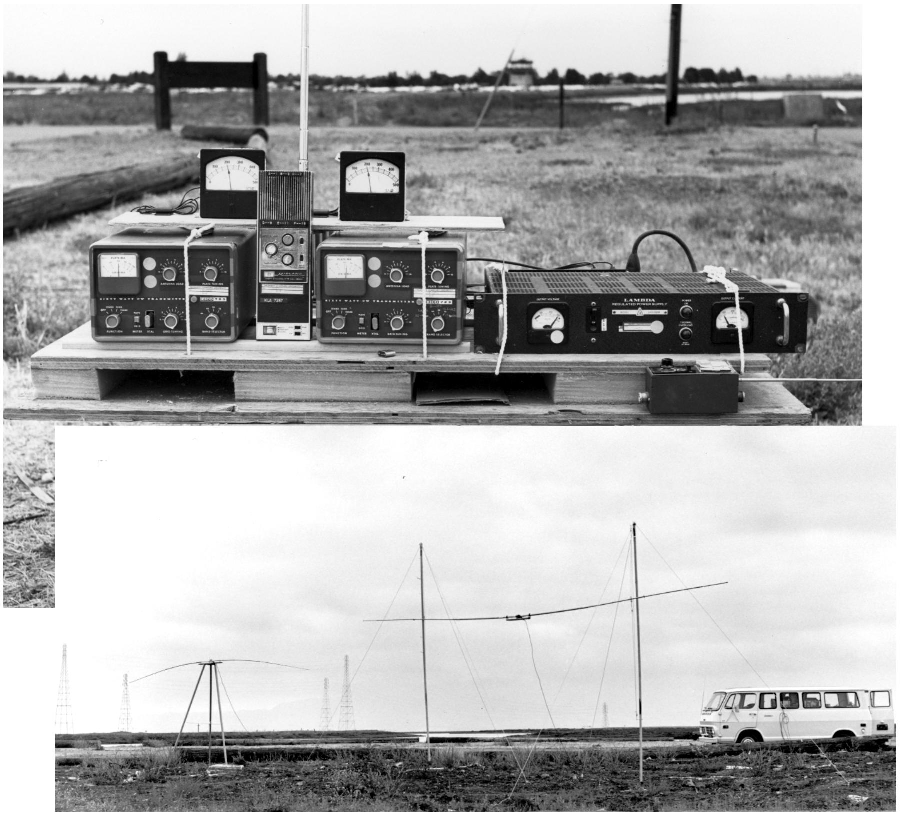


Figure 8-8. At the Palo Alto Airport, site of the first active stealth experiments. Shown are laboratory radar equipment and dipole antennas (May 23, 1972).

technique eventually caused the cancellation of the development program for that radar!

While in retrospect this may all seem straightforward, this test, or proof of concept, was the culmination of months of preparatory work that began as early as the mid-1960s. It was first necessary to learn about the basic nature of the reflected signal. What were the magnitude and variations of its amplitude and phase? Was the rate of variation too fast to usably assess or compensate for? Would the incident radar signal arrive via multiple paths that would produce untraceable fading? First, non-cooperating airplanes were used in gathering such data. Later, a single target, the SRI AeroCommander mentioned above, was moved to varying distances on the ground and then flown with no electronics on board. After the successful 1972 demonstration, it was necessary to introduce the means to automatically perform the tasks that the well-coordinated Lomasney did manually. The team was expanded to include those SRI staff familiar with digital algorithms and microprocessors.

Villard and others on the SRI radar cross-section (RCS) reduction team created over a hundred memoranda, and this library of knowledge formed the basis to seek long-term research sponsorship. SRI was able to get a considerable number of research contracts over the approximately two decades that this important technology evolved. While there were several sponsors for the work, the foremost of these was DARPA and their Military Service affiliate, the Office of Naval Research. SRI built an anechoic chamber, introduced complex models of military aircraft, and performed finite-element modeling of their complex structures to learn just how reradiation had to be tailored. The capabilities became so useful that very early on they were drawn under the cloak of secrecy. Thus, stemming from the freedom to explore a relatively simple but powerful concept, Mike Villard and his SRI program team made extraordinary contributions to the U.S. military capability.

Active Underwater Acoustic Stealth

Among Dr. Villard's various roles in the early 1970s was membership on the Navy's Research Advisory Committee. Therefore, it was natural that Villard's fertile mind would extend his notions about active RCS control to the underwater world of acoustics. But although one could make guesses about the parallels between electromagnetic and acoustic wave cancellation, Villard was not one to bring speculations before such a knowledgeable group if he didn't have to. So, before he proposed it, he first wanted to see if the same success he had with radar at the Palo Alto Airport could be replicated for sonar. Thus, SRI's second area of stealth had to do with water and acoustics. The analogy with the radar case seemed valid, and

Figure 8-9. At Searsville Lake near Stanford University, location of SRI's active sonar experiments. Shown are acoustic equipment, hydrophones, with Jim Lomasney and Ernest Aho of the SRI "Navy"(about 1972).

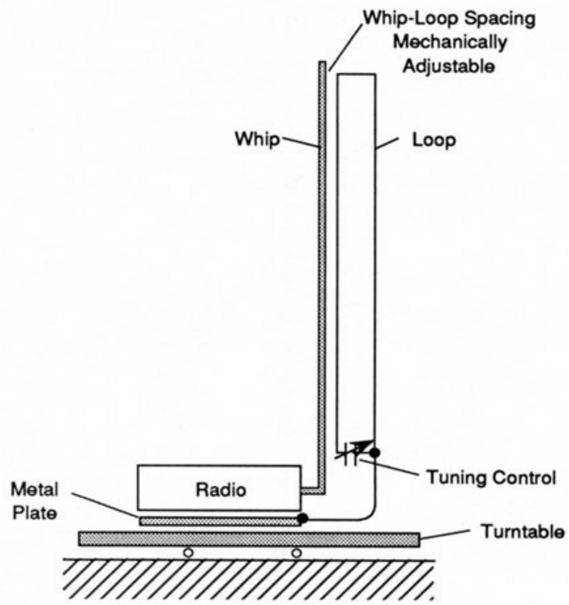
the U.S. submarine fleet, and to some extent its surface fleet, clearly had need to cloak themselves to enemy sonar systems.

The question, then, was: Can ships or submarines radiate acoustic energy whose direction and phase is such that it would cancel a sonar reflection in that same direction? Near Stanford University was a small placid lake whose bottom contained a lot of soft mud, which would be ideal for an acoustic experiment because it would help absorb unwanted signals (see Figure 8-9). This meant that the main signals would be those direct pathways between the sonar transmitter and its targets and their reflections, much as in deep ocean water. The team found some good hydrophones that SRI happened to be working on for the Navy and, within about 6 months following the radar experiments, they were in the waters of nearby Searsville Lake. Here, hydrophones replaced the radar and its antennas and a boat replaced the airplane, but otherwise the basic setup was very similar to that at the Palo Alto airport. With these sonar experiments, SRI obtained cancellation results similar to those it had achieved with radar.

The consequences for SRI of Villard's stealth-related innovations have been incalculable. Both investigations caused a flurry of activity by the military community and their important contractors to develop the underlying science and apply its consequent military benefits. SRI continued to pursue the acoustic and radar opportunities. The radar work at SRI lasted about 20 years and involved scores of talented researchers. Their collective outputs were, of course, classified, but their impact on both SRI and U.S. military capabilities was enormous.

Enabling a Warm Voice in a Cold War

Churchill's Iron Curtain analogy was as much a barricade against ideas and awareness as it was against ideologies and commerce. As the Cold War developed, the West decided it was useful to broadcast a more complete story of world events, and the Voice of America (VOA), created during WWII, was reenergized in 1950. The Eastern Bloc governments would endeavor to jam these transmissions to prevent contrary views or factual news from reaching their people. Because most of the VOA transmissions were shortwave, and because Mike Villard had enormous expertise in this area, he became a long-term technical advisor to the VOA. Through this relationship he became aware of



Source: SRI International

Figure 8-10. Schematic of a small directional shortwave Villard antenna capable of nulling a distant jammer.

how desperately the Soviet Bloc people had to struggle to listen to the many VOA radio channels. So, he decided to do something about it.

His idea was to build a *small* shortwave receiving antenna that would help reduce the influence of a jammer. This meant that the antenna needed directionality, which at these frequencies usually implied large dimensions—of the order of tens of feet—and thus outdoor installations. That, in turn, would reveal a listening capability to the local militia. Hence, it was important to make such equipment small, easily camouflaged, and, it was hoped, accommodated indoors.

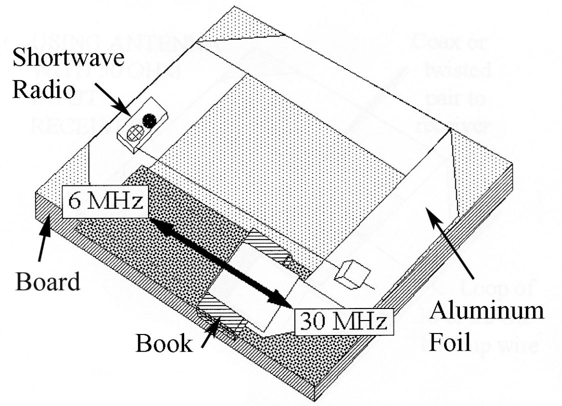


Figure 8-11. Very inexpensive, disposable shortwave Villard antenna capable of suppressing a local jammer.

First, under VOA sponsorship and then using SRI internal funds, Villard and a small SRI team developed such small antennas. One rough schematic, shown in Fig. 8-10, was intended mainly for sky waves—those shortwave signals reflected from the ionosphere.[O] If a radio jammer or other noise source was more local, such that its waves arrived along the ground, a horizontally polarized antenna was needed to reduce its effect. For this Villard designed an extremely simple, easily disposable, yet tunable antenna made of aluminum foil (see Figure 8-11).[P] Villard and colleague George Hagn continued the development of these very portable directional antennas until the anti-jamming purpose for which they were originally intended had ended.[Q,R] This end was defined by the winding down of the Cold War in the late 1980s.

Endnotes

[A] SRI's *Research for Industry,* 2(6), March 1950.

[B] SRI's *Research for Industry,* 6(6), July 1954.

[C] Ibid, plus in Joseph Stocker, "The Miracle Makers of Menlo Park," True Magazine, 1956.

[D] A note on *Communication and Ionospheric Research at SRI* by John Lomax, received December 1996, also indicates that for Bob Kulini of the U.S. Army Signal Corps, this contract began a two-decade relationship. His goal was to "establish an independent radio engineering research center" at Stanford/SRI. Also referenced in SRI's *Research for Industry,* 3(6), September 1951.

[E] This account was compiled by Harvey L. Dixon in a personal communication entitled "Civil Defense Research at SRI," dated November 25, 2003.

[F] Harvey Dixon, et al., *Comparison of Effective Biological Doses for Three Alternative Recovery Rates,* SRI Project No. 2690 for the Office of Civil Defense and Mobilization, 1959.

[G] The material and insight about SRI work in air-combat ranges was provided by two important principals in the work, John McHenry and Elliott Hinely.

[H] Major Jeff Grant, "War Games: Troops Train with GPS-Enabled Battlefield Simulation," GPS World, November 1977.

[I] "A Study of Command Control Communications," SRI Project 2841, sponsored by the U.S. Army Signal Corps, started April 23, 1959, for $116,400. Bell Laboratories was a subcontractor to the study.

[J] Conversation on January 11, 2002 with William T. Lee, who was present at the McNamara meeting.

[K] Some of this account came from a conversation with Leon Sloss (January 11, 2002), who was then a member of the SSC and present at the meeting. He later headed SRI's Washington, D.C. office.

[L] Some of the insight of this section came from a discussion with Joe Nanevicz on June 14, 2001.

[M] SRI's *Research for Industry,* 7(8), 2, September 1955.

[N] SRI's *Research for Industry,* 3(6), 4, September 1951.

[O] Villard, O.G., Jr., K.J. Harker, G.H. Hagn. *Interference-Reducing Receiving Antennas for Shortwave Broadcasts,* Final Report, Contract IA 22082-83, SRI Project 1255, SRI International, Menlo Park, CA, January 1987. Ms Cheryl Hagn also participated in this project.

[P] From http://users.erols.com/k3mt/hla/hla.htm and the hand of Michael Toia, who was Villard's technical contracting representative at the Voice of America.

[Q] Villard, O.G., Jr., *Miniature Directional Antennas for Improved Radio Reception,* SRI Business Intelligence Program Report D89-1347, SRI International, May 1989.

[R] Villard, O.G., Jr., G.H. Hagn, and J.M. Lomasney, "Converting a Small Standard Receiver into a Hand-Held Narrow-Aperture HF Direction Finder," *IEEE Antennas and Propagation Magazine,* 36(5), 25–29, October 1994.