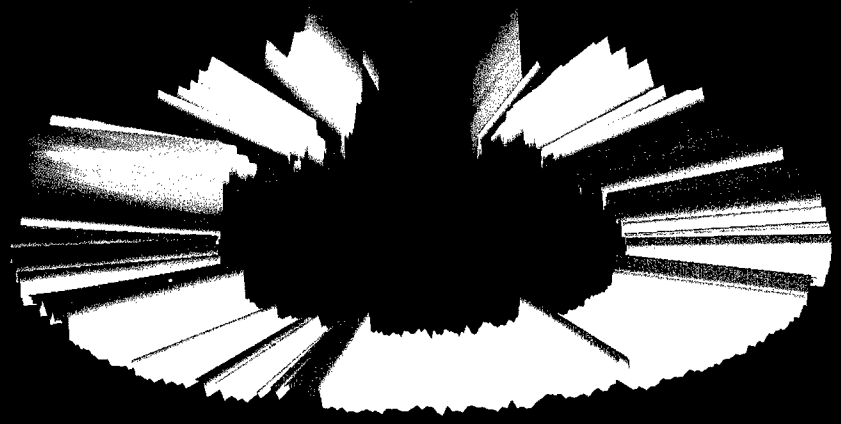
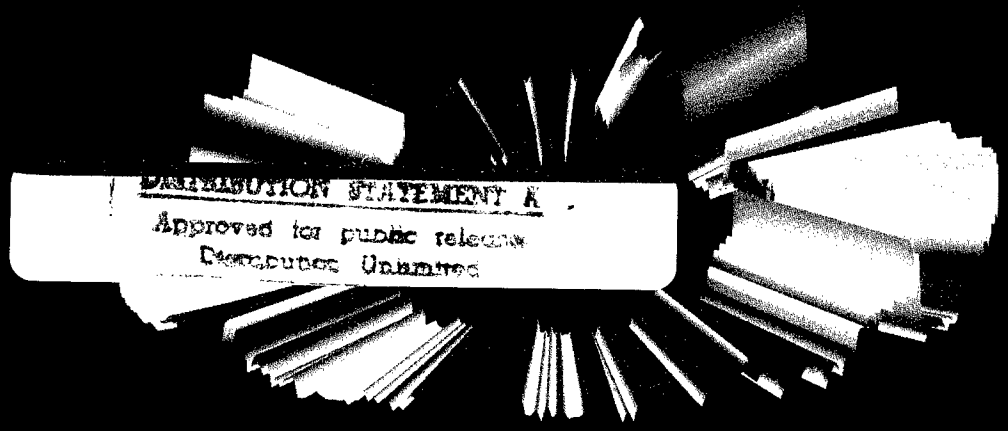
1993 Annual Report

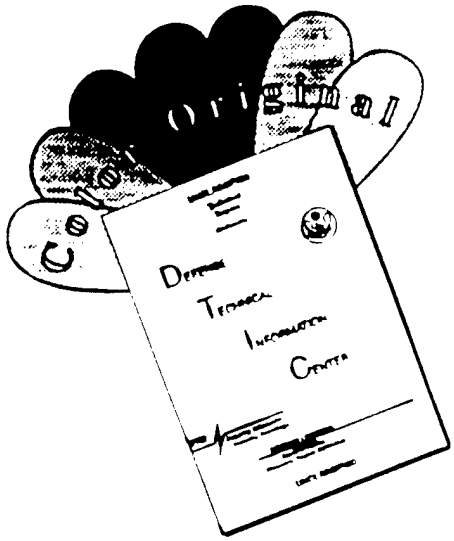




IDA Institute for Defense Analyses

Applying color visualization techniques, researchers at IDA's Supercomputing Research Center seek to enhance computer performance. The three consecutive views shown here represent memory usage in a supercomputer and are used as a tool by researchers to optimize the design of the processor/memory interface.

DISCLAIMER NOTICE



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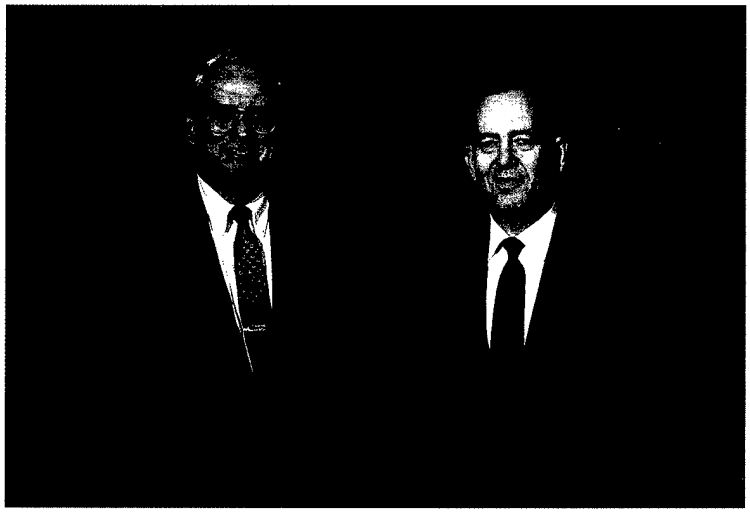
THE INSTITUTE

The Institute for Defense Analyses is a federally funded research and development center established to assist the Office of the Secretary of Defense, the Joint Staff, the Unified Commands and Defense Agencies in addressing important national security issues, particularly those requiring scientific and technical expertise. IDA also conducts related research for other government agencies on national problems for which the Institute's skills and expertise are especially suited.

MESSAGE FROM THE PRESIDENT

Much has been said and written about the changing world and the new challenges we face as a nation — but are these challenges new? Taken individually, many of today's most urgent problems are endemic: Balkan strife and bloodshed, violence and famine in the Horn of Africa, arms races in regional tinderboxes. None, unfortunately, is new. Other challenges, such as downsizing America's military while preserving readiness and transitioning the economy from a wartime to a peacetime footing, also have been faced several times before in this century. Yet viewed together against a backdrop that includes the widespread availability of nuclear weapons and the question of America's status as the sole superpower, these challenges aggregate to comprise a world that is very new.



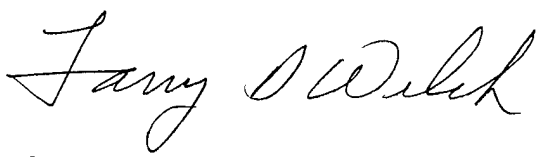
Larry D. Welch, President (right) and W. Jarvis Moody, Chairman

For those of us whose professional business is national security analysis, there are three compounding challenges. The first is to remain aware of and responsive to today's issues and priorities. For IDA this has meant increasing our focus on information systems, military readiness, and cost effectiveness — both in procurement of systems such as the C-17 and in defense infrastructure, dual-use technologies, weapons proliferation, and environmental problems. And because simulation holds the dual promise of serving as a valuable and relatively inexpensive adjunct to more traditional forms of training, and of permitting more sophisticated procurement decisions, it also has meant expending considerable effort to improve simulation tools and apply them to real-world problems.

The second challenge is that of approaching today's issues with an intellectually open mind, rejecting assumptions that may no longer be valid, while still heeding the lessons of history. Concerns about the proliferation of nuclear weapons in the third world have been voiced since the 1970s, yet nuclear bipolarity was the driving force in our thinking about deterrence and defense policy overall. Now we must fashion new theories and concepts to replace those of the old bipolar world. Genuine progress has been made in DoD and elsewhere; more needs to be done.

The third challenge arises from the collapse of the Soviet empire. With that collapse, American priorities have shifted. Today, fewer resources and less attention are devoted to national security. Yet because the issues we face are difficult, and the budgetary margin for error small, it is even more important that national security decision makers get the best possible analytic support. Thus the third challenge — and the primary one for IDA's leadership — is to ensure that the Institute continues to attract and nurture quality people so that our support of the Department of Defense and our other sponsors remains of the highest caliber.

The following pages offer highlights of our research program and attest to IDA's capability and commitment to address the challenges we all face.



General Larry D. Welch, USAF (Ret)

President

RESEARCH OVERVIEW

IDA's yearly program of research is a mixture of continuing analyses that address enduring problems and new starts in response to sponsor requirements. We categorize our work into six primary areas: technology assessments, systems evaluations, test and evaluation, force and strategy assessments, resource and support analyses, and high performance computing and communications. Overviews of each of these, with brief descriptions of representative studies, are given here.

TECHNOLOGY ASSESSMENTS

Maintaining technological superiority remains a cornerstone of US defense strategy. With defense budgets shrinking and technological opportunities expanding — rapidly in some areas — selecting the "right" technology investments requires comprehensive and current knowledge of both technological advances and evolving military needs. IDA continues to provide the scientific and technical support needed for the Department of Defense to make these difficult technology choices. Some recent efforts are discussed below, while others are covered in more detail under Areas of Special Interest.

Sensors and Observables

Ultra-Wideband Radar

The capability to detect targets obscured by dense foliage or placed underground may be critical to future warfare. Stimulated by the development of extremely fast, high voltage switches that permit the generation of very-high-power, ultrashort pulses, ultra-wideband (UWB) radars offer the potential for significant performance improvements compared to conventional microwave frequency sensors. We are studying the potential of UWB radars to detect hidden targets, examining key issues such as its capability to perform focused radar imaging through random media (tree canopies and soil, for example) and its capability to overcome heavy concurrent use of the same frequency bands by other radars.

IDA provides technical support to the Advanced Research Projects Agency (ARPA) in investigating the phenomenology, technology and potential applications of ultra-wideband radars. We have participated in expert evaluation panels, provided advice to help structure ARPA's current research program, and conducted specific technical analyses of clutter measurements, ground penetration phenomena, signal processing and radar system design.

Tactical Warning and Attack Assessment

The United States maintains a constellation of satellites known as the Defense Support Program (DSP) for the primary purpose of providing early warning of ballistic missile attacks. DSP satellites were to be replaced by the Follow-on Early Warning System (FEWS). Budgetary pressures led DoD to reconsider alternatives to FEWS, including upgraded versions of the DSP. IDA provided an independent assessment of the proposed DSP upgrades and evaluated other non-FEWS options, such as two alternate multispectral approaches. Our analyses focused on the technical feasibility, performance and costs of the alternative sensor systems. This work contributed to DoD's decision to restructure its program for developing and procuring systems for early warning of ballistic missile attack.

Materials

The ability to produce advanced materials at low cost is critical to the performance and affordability of future defense systems. IDA is at the forefront of assessing the expanding opportunities for the production and application of advanced materials. One material of current interest is a titanium alloy reinforced with continuous ceramic fibers, which is being developed for possible use in advanced airframe structures and in the rotating components of new gas turbine aircraft engines.

Other efforts sponsored by ARPA include the evaluation of advanced ceramic fibers, ceramic matrix composites, advanced monolithic ceramics and, most recently, free-form processing of complex ceramic parts, which offers the potential for flexible and low cost manufacturing processes. We also are investigating techniques for inserting ceramic parts, such as roller or ball bearings, into existing hardware components, and we are continuing to assess the development of

thick-section polymer-matrix composite structural components for advanced maritime applications.

In a related area, the Institute has played a significant technical role in helping ARPA formulate new programs in fuel cell technology for defense needs — an area which has been frustrated for decades by the extreme materials design problems associated with the use of hydrogen. With IDA support, ARPA is implementing programs to design advanced fuel cells based upon a family of new materials that use ordinary fuels such as gasoline, diesel, or jet fuel.

Electronic systems are evolving at a very high rate. Processing capacities are doubling every few years. The development of new electronic devices, along with parallel improvements in semiconductor fabrication, are expected to lead to greater performance and lower cost for future military systems. Our current work in this area is focused on improved semiconductor fabrication, thus helping ARPA develop manufacturing techniques that lower the costs of fabricating DoD-unique semiconductors typically produced in relatively small numbers.

Computing Systems and Software

Software Inspections

Up to 40 percent of the cost of DoD software development is devoted to correcting defects. The commercial industry "best practice" of formal software inspection has resulted in an effective process for reducing defects throughout software development. When combined with traditional testing practices, this inspection process routinely and significantly improves the quality of fielded systems while reducing their cost. A common practice in commercial industry, formal software inspection is not used routinely by DoD contractors.

In 1993, the Ballistic Missile Defense Organization asked IDA to assist in improving the awareness and use of the software inspection process. We assessed the inspection process, examining the potential benefits and cost savings of software inspection in comparison with traditional review processes. We also assisted in transitioning the inspection process into the ballistic missile defense program.

NATO Ada Software Programming Environment

IDA's experience in using the Ada programming language, and in conducting technical risk analyses of state-of-the-art software development tools, has been essential to our ongoing support for the NATO Special Working Group on Ada Programming Support Environments. Working with researchers from participating NATO nations, we have helped produce a collection of advanced development tools for using the Ada programming language. Another NATO project demonstrated that through the better use of common tools and integration support, larger numbers of individuals and companies within the NATO nations can work effectively to accomplish military software projects more rapidly.

Natural Language Information Extraction

The Institute is providing analytic support to the joint ARPA/NSA-sponsored Tipster project, which is exploring the technology for computer-based automated extraction of information from written text. This is a strikingly challenging area, given the complexity and subtlety of human language. We created templates for data extraction that have been applied successfully to English- and foreign-language articles about joint business ventures and microelectronics fabrication. Another project used extracted information from several thousand test articles to create a "human-derived" baseline against which various computer extraction

systems will be evaluated. Some of this information is being used to develop new extraction algorithms and to test additional information extraction approaches.

New Technologies in Defense Systems

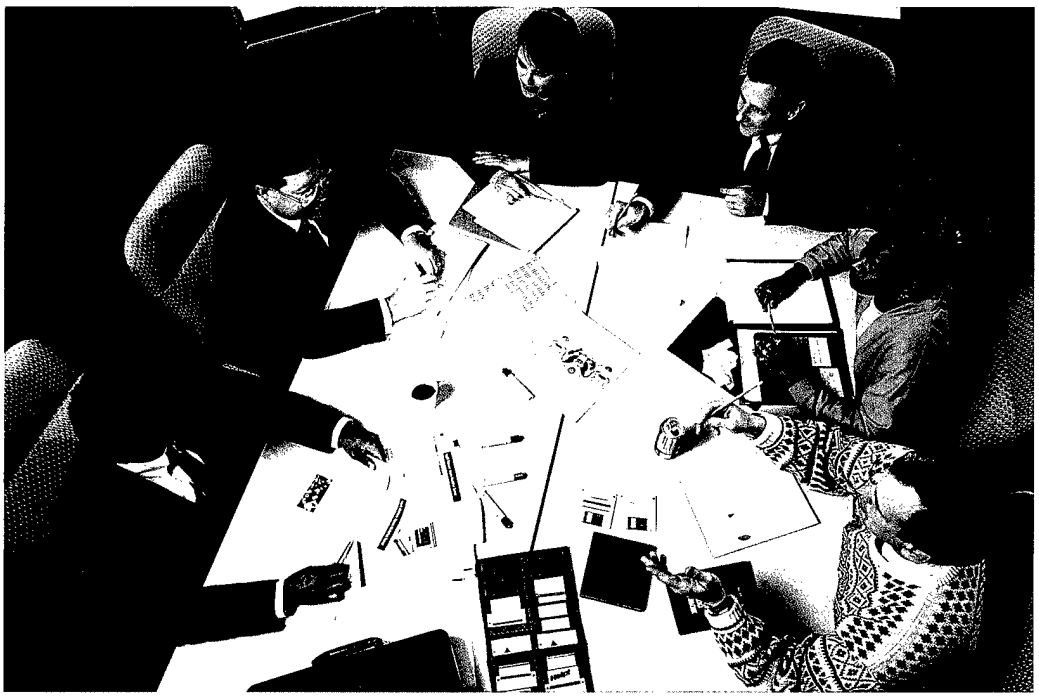
Advanced Artillery Technologies

The Army's Advanced Field Artillery System is intended to improve the rate of fire, the range, and the accuracy of US medium class artillery. To achieve the desired rate of fire, the Army is developing a liquid propellant with low toxicity, high-energy density, and low susceptibility to inadvertent detonation. The United States, the United Kingdom and Germany are cooperatively developing a solid propellant, Unicharge, as an alternative to the liquid propellant.

Our analysis of propellant technology found that the susceptibility of gun overheating, and the resulting increased rate of wear, represented a critical technical program risk, regardless of whether a liquid or a solid propellant is used. This vulnerability is not attributable to the propellant but is a consequence of the rate of fire and range objectives. The liquid propellant does, however, introduce some additional risks, such as creating a corrosive environment inside the gun, increased complexity, and potentially unstable pressure oscillations. These risks are serious, but the continued development of the liquid propellant gun could provide considerable insight into the technological challenges posed by other future-generation guns using electric or electro-thermal-chemical propulsion.

Ship and Submarine Propulsion Technologies

Significant advances in the design of naval propulsion systems have raised the possibility of introducing improved performance at a lower cost in both Navy surface ships and submarines. To examine this possibility, DoD asked IDA to conduct a two-phased evaluation of alternative naval propulsion systems.



Animated discussions produce innovative approaches to solving complex technical problems.

In the first phase, we evaluated the performance, development status, and projected costs of a broad range of propulsion system technologies. In the second phase, we assessed the technical and military utility of the selected propulsion technologies. The overall study is intended to help DoD identify the most appropriate cost-effective propulsion systems for several important types of ships and submarines in the future fleet.

Science and Technology Planning

IDA has supported DoD in developing an overall investment strategy, setting program priorities, and reviewing specific technology programs to determine future directions for DoD's science and technology (S&T) efforts. From mid-1991 until the end of 1992, we contributed technical and analytical expertise toward the development of the *Defense Science and Technology Strategy*, the DDR&E's top guidance for the S&T program. We assisted in coordinating and developing the *Defense Technology Strategy and Action Plan* and we continue our efforts on the *Army Science and Technology Master Plan.* These plans represent significant progress towards the Department's goal of producing a unified strategy for the S&T program.

In late 1993 and in support of the Director, Defense Research and Engineering, we began work on the revised science and technology strategy. This effort is being conducted in close consultation with the DDR&E and the senior executives responsible for science and technology programs in the Services and Defense Agencies. The goal is to produce a high-level plan that will set the strategic direction and provide the basis for management oversight for the $8 billion DoD science and technology program.

International Technology Issues

Our understanding of the national security implications of technology transfer provides IDA with the basis for addressing international technology issues. At the Vancouver Summit in April 1993, Presidents Clinton and Yeltsin expressed their determination to promote access to each other's markets by removing impediments to trade and investment. The broad liberalization of export controls, and the new role of Russia, had an important impact on the Coordinating Committee for Multilateral Export Control (COCOM).

In anticipation of sweeping changes, the Director of Multinational Technology Programs asked IDA to develop a conceptual framework and specific procedures for further liberalizing the COCOM International Industrial List. Working with technical experts from Government, industry, and academia, we have proposed a new priority list of export-controlled items that could facilitate greater economic trade of some items, such as workstation computers, but retain controls on those technologies considered to be critical to the military. We likewise conducted the supporting technical analyses for categorizing the COCOM International Munitions List (IML), which was ultimately used by DoD in preparing the IML Very Sensitive List. In both cases, our proposals were used by the Government as the technical basis for negotiations with COCOM partners.

As the sucessor organization replacing COCOM evolves — with broadened membership and national prerogatives — IDA will continue to support DoD, providing draft export control proposals and on-site technical support at multinational negotiations.

SYSTEMS EVALUATIONS

The emphasis of US national security planning has shifted from worldwide conflict with the Warsaw Pact to geographically constrained wars against regional powers. Thus, IDA's systems evaluations now focus on helping DoD determine which capabilities would be most useful in such regional conflicts. Several evaluations have been aimed specifically at finding remedies for deficiencies uncovered during the Persian Gulf War.

In addition, the current acquisition process stresses the use of cost-effectiveness studies to assist in decision making at system milestones. Because of the importance of these so-called Cost and Operational Effectiveness Analyses, and IDA's role in conducting them, they are reported on under Areas of Special Interest. Other systems evaluations are discussed below and cover four broad areas: strategic systems, tactical systems, command, control and communications, and information systems and software.

Strategic Systems

Assessment of B-1B Defensive Avionics

The Air Force is upgrading the B-1B bomber for long-range conventional missions to include new defensive avionics and the capability to carry various conventional weapons. To help determine which electronic countermeasure systems could best meet the B-1B's self-protection needs without undue risk or cost, Congress directed IDA to perform an independent assessment.

Using the considerable data and knowledge available from our previous studies of the B-1B, we have carried out a detailed evaluation of eight concepts for upgrading the bomber's defensive avionics system. The analysis has examined the use of radar warning receivers and missile warning systems to avoid threats, the effectiveness of jamming against hostile target acquisition radars, and the performance of terminal countermeasures against airborne missiles. Our results have been used by OSD and the Air Force in their selection of options to be pursued in the program's risk-reduction phase.

Conventional ALCM on the B-1B

In addition to changes in the B-1B's defensive avionics, the Air Force and OSD are examining a variety of weapons that the bomber might carry. Of particular interest is the Conventional Air-Launched Cruise Missile (CALCM), a modified version of the nuclear-armed Air-Launched Cruise Missile (ALCM-B) carried by B-52 bombers. In the FY 1993 Defense Appropriations Bill, Congress directed a review of the costs, schedule, and technical requirements for modifying at least half of the B-1B fleet — about 50 aircraft — to carry the CALCM. OSD asked IDA to conduct the study.

Our analyses showed that the B-1B could be modified to carry the CALCM internally with little technical risk and at modest cost; modifying the B-1B to carry CALCMs externally would entail considerable technical challenge and would be significantly more costly. The study also identified the potential implications of equipping the B-1B with CALCMs for compliance with the START I and START II treaties.

Tactical Systems

Assessment of Rapid Crisis Response Capabilities

Future crises may require the rapid projection of US military force to distant areas without the advantages of significant in-place forces or local bases. In such situations, significant initial US firepower could be required from long-range bombers and forward-deployed naval forces — carrier aircraft or ships and submarines equipped with long-range cruise missiles. To determine whether these forces are being adequately equipped, OSD asked IDA to conduct a comprehensive assessment of the

IDA provides systems evaluations, such as that conducted for the helicopterborne dipping sonar, for the full range of acquisition programs.

current and future capabilities of bombers, naval attack aircraft, and sea-based cruise missiles to attack land targets in a rapid response situation.

We have examined potential targets and air defenses associated with a variety of crisis response situations, ranging from limited strikes against isolated fixed targets to larger-scale attacks on invading ground armies. Using this information, we have estimated the capabilities of mixes of bombers, carrier-based attack aircraft and cruise missiles. We also have assessed how crisis response capabilities could be influenced by intelligence support, mission planning, targeting, and post-strike reconnaissance as well as aircraft survivability and weapons effectiveness. In each of these areas, we have identified current limitations, assessed the contributions of planned improvements, and suggested enhancements that could improve US capabilities to respond should a crisis arise.

Helicopterborne Dipping Sonar

As the threat to US security has changed from global to regional, it became unclear whether detection systems designed to find quiet Soviet submarines would be suited for use against the non-nuclear submarines that US forces might face in regional contingencies. To address this concern, Congress asked OSD to assess the capability and cost of the Airborne Low Frequency Sonar (ALFS) system and other alternatives against new threats.

At OSD's request, IDA has evaluated the potential combat effectiveness of helicopters equipped with alternative detection systems, including the ALFS system, the current dipping sonar and several others. We have studied a variety of missions and environmental conditions typical of those expected in regional conflicts. By combining our results with estimates of system costs, we have found ALFS to be more cost effective than other alternatives. Based on this IDA study, OSD has recommended that development of ALFS be continued.

Nonacoustic Antisubmarine Warfare in Regional Conflicts

Throughout the Cold War, the Navy conducted research on a wide variety of nonacoustic techniques that might be used to detect submarines, including radar, infrared, electromagnetic, and optical sensors. Some of this activity was aimed at developing nonacoustic detection systems, but the primary purpose was to ensure that US ballistic missile submarines were secure from detection by nonacoustic systems that might be built by the Soviet Union. Today, the focus of nonacoustic research has been redirected towards attaining an effective submarine detection capability.

Although the Navy has traditionally directed all antisubmarine warfare (ASW) research activities, in 1990 Congress established a separate national nonacoustic ASW research and development program within OSD. As part of that effort, IDA was asked to help establish operational requirements for nonacoustic submarine detection systems within the context of a regional conflict and to assess the ability of the various nonacoustic sensor technologies to fulfill those requirements. The results of our work are being used by OSD in allocating R&D resources among the alternative technologies.

Command, Control & Communications

Tactical Signals Intelligence Architecture

The experience of the United States during the Persian Gulf War reaffirmed the importance of providing field commanders with timely and accurate intelligence of tactical operations. Much of this information is obtained from the tactical airborne signals intelligence (SIGINT) systems operated by the military Services. By furnishing timely

coverage of long-range targets, these systems offer a capability not provided by national or theater-level intelligence systems, but they must be employed efficiently if they are to provide effective intelligence.

At the request of the National Security Agency, IDA conducted an assessment of the interoperability among the Services' airborne SIGINT systems and identified options for enhancing their operational availability and utility. We demonstrated that joint interoperability provides the task force commander a number of important advantages — it facilitates early deployment into the area of operations, it enhances aircraft survivability, and it increases the range of coverage. The results of our analyses are being used by DoD to develop the mission needs statement for joint interoperability of the Services' SIGINT systems.

Aviation Command and Control in a Joint Task Force

The Persian Gulf War also demonstrated the need for greater integration and interoperability of joint Service aviation command, control, and communications (C^3) systems. The Defense Information Systems Agency and the Joint Staff asked IDA to assess aviation command and control (C^2) functionality and system support in a Joint Task Force (JTF). Our study focused on three areas: joint operational concepts and procedures for aviation C^2, emerging requirements for joint C^3 system capabilities, and existing and planned C^3 system support for joint aviation operations. We paid particular attention to the increasingly complex relationship between the extended-range ground attack systems now available to JTF commanders and the joint targeting process used to assign these weapons to targets.

Our analysis focused on the evolving roles of the JTF commander, the Joint Forces Air Component Commander, the Joint Targeting Coordination Board, and the JTF component commanders in prioritizing targets, allocating resources, and planning and executing air missions. With this information, we derived the associated needs for C^3 system support, and proposed a new aviation C^2 architecture that enhances joint operations by exploiting emerging technologies in sensor and intelligence systems, computer-based mission planning, and high-speed data communications. We also recommended actions to facilitate the timely and coordinated employment of these new technologies.

Fire Support Data Model

In 1991, DoD mandated the development of data models to support department-wide data standardization. By standardizing the meaning and relationships of data, such models help achieve interoperability of information systems and facilitate the design of efficient and accessible databases. Data models also support direct database-to-database exchange, the key data distribution mechanism for modern tactical command and control information systems. These models likewise provide the basis for command and control interoperability standards, both within the United States and among allied nations.

At the request of the Defense Information Systems Agency, IDA devised a methodology for developing data models. We then used this methodology to construct a prototype model for command and control of the fire support function. The model supports most currently defined joint, multinational, and Service-specific fire support information and information exchange requirements and has the potential to support parallel development and integration of other C^2 data models. The Joint Staff recently asked us to modify our model for use as the DoD C^2 Core Data Model.

Counter-Drug C^3

One priority of the National Drug Control Strategy has been to improve ways of sharing and using counter-drug information among

law enforcement agencies. At present, this capability is handicapped by the absence of accepted data standards that hinder exchanging data among the various agencies.

To improve this situation, IDA developed prototypes for formatted message standards that could facilitate automated information exchange. Based on a careful examination of the various law enforcement databases, we identified blocks of commonly held information that might usefully be exchanged among agencies — records of events and descriptions of people, vehicles, and organizations. We also specified the relevant details associated with each item and created comprehensive and coherently organized data formats. These formats will facilitate the exchange of information among agencies involved in drug enforcement.

Information Systems and Software

Automatic Test Systems

The value of DoD's inventory of automatic test systems supporting the manufacture and maintenance of weapon systems exceeds $50 billion. The majority of the existing equipment is unique to specific weapon subsystems. The F-15 fighter aircraft, for example, requires 24 different automatic test sets for avionics repair. Given the cost of acquiring and operating this diverse test inventory, DoD is questioning the need for so many special-purpose systems. At OSD's request, IDA evaluated alternative investment strategies based on the application of common automatic test systems. The evaluation covered 15 major weapon systems.

On the basis of extensive economic, industrial and technical analysis, we proposed a new acquisition strategy that would limit the number of automatic test system configurations to a few common families supporting the full variety of DoD mission areas. This approach would reduce the number of unique automatic test systems by a factor of five. The cost of these systems could be further reduced by integrating currently available commercial off-the-shelf test equipment in DoD-unique packaging. The combination of these two factors could reduce program acquisition costs by 20 to 30 percent and, over the next decade, could reduce total expenditures for automatic test systems by 15 to 20 percent. DoD is currently developing a new policy for automatic test system acquisition that reflects this proposed strategy.

Software Reengineering Methodology

As part of the Corporate Information Management Initiative, DoD is looking for ways to reduce the operating and maintenance cost of its information systems, which currently contain about 1.4 billion lines of computer code. Much of this code resides in aging "legacy" systems that were built before modern software engineering and data management techniques were available. Many of these systems are written in low-level languages and are designed to run on large mainframe computers. As new capabilities have been added to the legacy systems, they have become more difficult and more expensive to maintain.

With the advent of smaller computers and new system architectures, DoD must decide whether to rebuild, that is, "reengineer" these older systems or continue using them as they currently exist. Reengineering is advisable only if it results in better performance, upgraded capabilities and lower operational costs. To aid in this process, we developed a methodology to assist DoD managers assess the costs and benefits of reengineering their legacy information systems. Our methods are being applied DoD-wide, providing for consistent quantitative evaluation in the redevelopment and acquisition of information systems.

TEST AND EVALUATION

Since its founding, IDA has supported the Office of the Secretary of Defense in the test and evaluation of major weapons systems. We provide the primary analytical support for the Director, Operational Test and Evaluation (DOT&E), and we examine issues concerning live fire, developmental, and joint testing.

Operational Test and Evaluation

IDA's support to DOT&E covers all types of acquisition programs, including conventional land, naval, and air warfare systems; strategic and space systems; command, control, and communications systems; and major automated information systems. Our activities uphold two major DOT&E responsibilities. First, we assist OSD in assessing the adequacy of Service OT&E plans — analyzing testing methods, threat systems, the test environment, instrumentation, and system performance throughout the system development process. Second, our analysts monitor operational testing and conduct detailed analyses of test results, addressing issues related to the performance of the systems being tested as well as the adequacy of the tests. Our assessments are critical inputs for the DOT&E reports to the Secretary of Defense and Congress.

Land Warfare Systems

IDA has assisted the Director, Operational Test and Evaluation in improving the quality of land warfare testing by preparing realistic test and evaluation concepts early in the development process. During the past year, we participated in planning for early user tests of the Short Range Unmanned Aerial Vehicle and the Joint Surveillance Target Attack Radar System ground station. Our observations of potential system performance and lessons learned provided insight into the scope of testing needed to support full rate production decisions for these systems. We also participated in operational tests for the M109A6 Paladin self-propelled howitzer and the Palletized Load System, providing independent assessments of the operational effectiveness and suitability for the DOT&E reports to the Secretary and Congress.

Naval Warfare Systems

IDA developed concepts for the test and evaluation of the Navy's New Attack Submarine, emphasizing greater realism and free play while retaining a quantitative approach to evaluation. We developed an evaluation plan for the upgraded Mk 48 Advanced Capability torpedo, and we monitored and assessed the developmental and operational testing of the Surveillance Towed Array Sensor System Low Frequency Active.

During 1993 we monitored preliminary operational testing of the Tomahawk Theater Mission Planning Center Upgrade, which supports targeting, navigation, and guidance for the land attack variants of the Tomahawk cruise missile. An important consideration for this test was the approach for using simulations to assess system performance. The Navy accepted our recommendation to use two independent sources of simulations for this purpose.

Air Warfare Systems

Over the past several years, IDA has been monitoring operational testing of Radar Warning Receivers. This effort continued during 1993 with the test and evaluation of upgraded versions of the ALR-69 and ALR-67(V)2, the receivers carried on the F-16 and F/A-18 aircraft, respectively. In addition to providing evaluations of these systems, we identified improvements in test procedures, instrumentation, data collection and data reduction that can be applied in future test programs.

Credible operational testing of electronic warfare equipment is particularly difficult, requiring test conditions that provide realistic stimuli to the systems being tested and allow accurate observation of the effects on threat systems. An opportunity to improve our understanding of such conditions arose this year when the Defense Intelligence Agency sponsored an exercise involving multiple US aircraft employing electronic countermeasures to attack targets defended by an integrated air defense system. The exercise scenario was more complex than that normally represented in an operational test. We assisted in the conduct of the exercise, and we currently are analyzing the results. This experience has given the IDA research community additional insights into scenario elements that produce interactions with electronic warfare systems and that should be provided during operational testing. Such insights will enhance DOT&E's ability to judge the adequacy of proposed operational test programs.

This year we also participated in testing activities related to a variety of other aircraft programs. We helped DOT&E plan the operational test program for the Advanced Tactical Fighter (F-22), which underwent a significant program restructuring. We have provided support for the Navy's F-14D — soon to enter Phase II of its operational evaluation — and we have assessed the latest operational test data for the Navy's F/A-18 Radar Upgrade Program. We also assessed the operational effectiveness and suitability of the Air Force's C-17 transport based on the first year of flight test.

Strategic and Space Systems

The Institute's research on strategic systems has shifted focus in response to DoD's increased emphasis on the tactical capabilities provided by strategic systems. This year we were involved in planning flight tests and identifying test and evaluation activities for the Theater High Altitude Area Defense interceptor and the Patriot missile upgrade. Additionally, we provided DoD with a test concept and evaluation plan for strategic bombers employed in conventional missions. This effort was motivated by Congressional language calling for a test plan that would both establish the baseline conventional capabilities available with the existing force of B-1B and B-52 bombers and address the potential of future upgrades.

The Institute likewise has been active in the test and evaluation of several major space systems including the Cheyenne Mountain Upgrade program, the Consolidated Satellite Operations Center, the Navy's Milstar terminals, and the UHF Follow-on satellite system.

Command, Control, Communications and Intelligence (C^3I) Systems

Our C^3I systems analyses of the operational test for the second-source radios of the Single Channel Ground and Airborne Radio System contributed to the Defense Acquisition Board (DAB) decision to proceed to full rate production. The All-Source Analysis System (ASAS) Block I configuration was tested in 1992 with unfavorable results. This year, we helped develop test and evaluation concepts for a modified ASAS. We also monitored three field exercises — including one in Kuwait — for the Army's Enhanced Position Location and Reporting System, and provided an operational assessment thereof.

The high-capacity, secure, jam-resistant Joint Tactical Information Distribution System (JTIDS) completed an operational test in early 1993. Because of concerns that operational testing has been inadequate to date, IDA developed a test concept focusing on quantitative assessment of JTIDS enhancements to battle group mission effectiveness. This test concept is being considered for operational testing in 1994 to support the Navy's full rate production decision.

We also analyzed test results for the E-2C radar upgrade, which is designed to increase the E-2C's detection capability over land and in the presence of jamming. These results will be used in DOT&E's assessment of the E-2C for the full rate production decision. And we developed a mission-oriented test concept for the Radar System Improvement Program of the E-3 Airborne Warning and Control System.

Major Automated Information Systems

Over 25 major automated information systems are currently under review, representing a broad range of computer-based systems providing administrative, logistical, and maintenance support. As DoD moves toward more efficient systems for information management, our research in this area is expected to expand accordingly.

IDA analysts are helping resolve fundamental operational test issues related to information systems. For example, the Composite Health Care System, designed to automate all medical and administrative functions at military hospitals and their outlying clinics worldwide, recently modified its program objectives. DoD has developed a PC-based system for smaller facilities, while it continues to deploy mainframe-based information systems to the larger hospitals. Our analyses led to the development of more effective evaluation techniques for both systems, including significant revisions to mainframe-oriented test concepts.

During 1993 we assisted OT&E in its oversight of operational testing of the Defense Logistics Services Center Modernization program, which maintains the Federal Supply Catalog used by the Services, other Federal agencies, and allied countries. Through our efforts, the original test plan was expanded to address additional critical issues, including the system's peak-load performance.

Live Fire Test and Evaluation

Live Fire Test and Evaluation addresses the vulnerability of US weapons systems — with particular attention to minimizing personnel casualties — and the lethality of munitions and missiles. These evaluations place special emphasis on structuring realistic tests, assessing results in an operational context, and identifying design flaws for corrective action. OSD is required by law to submit an independent live fire assessment to Congress before any program can enter full rate production. Again this year, we helped define the characteristics of acceptable test and evaluation programs, and we supported OSD in reviewing more than 40 test programs and in preparing independent assessments for five completed tests. One armored vehicle evaluated this year was the M109A6 Paladin self-propelled howitzer. The Paladin test identified a potential vulnerability, the M109A6 design was altered, and the vehicle was retested to demonstrate the correction.

Unlike ground combat vehicles, aircraft and ships have not been subjected to destructive testing of the full-up system at expected threat levels. For these programs, our efforts continue to define alternatives to live fire testing of the full system that balance test realism against the high costs of destructive testing.

Defining appropriate test targets is a major challenge for lethality tests as well. Typically, available surrogates represent only selected features of threat systems. Lethality tests of the Hellfire II anti-armor missile, for instance, used targets representing specific shotlines projected for future tanks. The live fire test program for the M830A1 tank-fired round, on the other hand, used a fully functional foreign helicopter with which to test lethality under near-miss conditions. For both programs, analyses conducted at IDA assessed lethality against the full spectrum of expected threats.

Developmental and Joint Test and Evaluation

We continue to support the Director of Test and Evaluation in the areas of developmental and joint testing. This year, several efforts underpinned the Director's involvement in department-wide reviews of the defense program, including the Bottom-Up Review. We also analyzed alternative policies for the use of test and evaluation facilities by DoD and private users, and for future NASA-DoD cooperative development and shared use of joint test and evaluation facilities.

The Director has begun a major effort to improve the effectiveness of the developmental test process. Several IDA projects support that goal. One focuses on improving the policies, processes, methods and procedures that guide the oversight of developmental testing for major acquisition programs; another examines how to make better use of developmental testing in identifying possible operational effectiveness and suitability problems early in the development cycle. Based on case studies and a review of development test documents, our analysis finds that developmental testing is often not effectively linked to operational performance goals, and our study recommends ways to improve that linkage, thereby increasing the chances for successful operational testing.

Another effort focuses on defining early indicators of technical and schedule risks associated with the development of programs with significant embedded software. Our analysts defined three types of indicators: those associated with the development and management process; those associated with the attributes of the software being developed and the capabilities of the developers; and those that could be identified from the quantitative management data used to measure and assess program status and progress. These risks and associated indicators were compiled in a handbook for use by DoD acquisition officials.

IDA also helps design and evaluate joint tests. For the ongoing test of Joint Air Defense Operations/Joint Engagement Zone concepts, we provided an independent analysis of the 1992 field test, monitored the planning and conduct of the 1993 test, and participated in the design of the next year's test. Our analyses contributed directly to the tests' success, and our support is being used as a role model for other joint tests. Likewise we developed a test concept for the proposed Theater Missile Defense joint test, and proposed a methodology for conducting such a test.

FORCE AND STRATEGY ASSESSMENTS

The Institute is involved in assessments of broad national security policy, particularly those that require a comprehensive understanding of defense technologies and the uses and capabilities of military forces. Our research is directed toward issues of military strategy, operational doctrine, force planning and support arrangements as they relate to new challenges facing the Department of Defense. Such analyses assist DoD in formulating its response to the evolving national security environment, while ensuring that IDA's total research program keeps pace with the Department's changing needs. This section highlights recent efforts related to weapons proliferation and control, contingency force planning, and the evolution of the Former Soviet Union.

Weapons Proliferation and Control

The Bottom-Up Review cites the proliferation of nuclear, biological, and chemical weapons as one of the preeminent dangers facing the United States. Russia and several of the former Soviet republics still maintain sizable nuclear arsenals. Estimates indicate that at least 20 other nations, beyond the five declared nuclear-weapon states, possess or have the potential to acquire nuclear weapons. Equally alarming, increasing numbers of likely adversaries have chemical, biological and advanced conventional weapons. In the hands of regional aggressors, these weapons present significant challenges for US forces and for America's ability to protect its interests during regional crises. Thus, efforts to halt proliferation, to counter proliferation, and to pursue cooperative threat reduction measures have become increasingly important.

Deterring and Defending Against Biological Warfare

At least 14 countries are believed to have undertaken research, production, or weaponization of biological agents in violation of the 1972 Biological Warfare Convention. Biological warfare technology is similar to that used in legitimate commercial endeavors so it is difficult to detect clandestine violations of the treaty. Thus there is a need to focus attention on biological warfare and bio-terrorist threats, and to develop programs and policies to improve US defenses.

We have been examining alternative ways to reduce the risks posed by foreign biological warfare developments using a three-part approach. First, we are analyzing discrete elements of the issue: threats, the adequacy of current US programs and policies, and how current policies, doctrine, force structure, and programs can be brought together into a single coherent strategy for deterrence and defense.

Second, we have sponsored a series of conferences — bringing together representatives from Government, academia, and industry — that addressed specific areas where gaps in US biological defenses are apparent. To date, topics have included biological warfare defense doctrine, intelligence on biological threats, and methods that might be used to preempt the use of biological weapons. Future conferences will address the foreign production of biological weapons, the integration of biological warfare programs, and options for strengthening the Biological Warfare Convention.

Third, we have developed scenarios for a series of wargames addressing a broad range of threats posed by foreign biological warfare programs. These games are intended to highlight gaps in US biological defenses and help focus the attention of the defense community on the most critical issues. The wargames span the spectrum of threats, ranging from those posed by domestic terrorists to those posed by highly developed foreign state-sponsored biological warfare programs. Taken together, our approach to this important national security problem is informing, and will help shape, the Government's efforts to meet the challenges posed by the spread of biological warfare capabilities.

Conventional Arms Control

We recently completed an analysis of how arms control has been changing and of its potential utility in serving future US security needs. Our study shows that the primary value of arms control has shifted away from reducing direct and immediate threats to the United States and toward reducing threats posed by regional states to one another. We postulate that US support of regional arms control will be as a facilitator rather than as a state whose forces are directly affected — a role that will be far more difficult to play.

Nonetheless, it will be important for the United States to remain involved and supportive of regional arms control efforts, for a number of reasons. Regional arms control can help to maintain regional balances of power that make war less likely. It can reduce the risks, and thus increase the credibility, of international intervention to stabilize regional crises. And regional arms control can increase the warning time of emerging trouble, thus increasing the prospects for timely and effective international political action. Our efforts also identify a wide variety of regional, technical, and peacekeeping initiatives to further US security interests.

Monitoring Arms Control

Under the START agreement, the United States can visually inspect re-entry vehicles. A research team from IDA joined representatives from DoD and DoE labs, OSD, and industry to evaluate proposed technologies that might be used to assist in the conduct of these inspections. For this evaluation, IDA has provided assessments of the cost and manpower implications of the alternative approaches.

In a related effort we have examined the possibility of using various types of sensors as an adjunct to manned inspections. In cooperation with representatives from other agencies, we have helped identify options and estimate possible savings that could be realized from adopting such approaches. The results of both studies have been used by DoD in shaping its ongoing research and development program.

Contingency Force Planning

Contingency force planning is now directed at the threat posed by regional aggressors. US forces are being restructured — in size, composition, and doctrine — to meet regional challenges. The United States is also looking to technological innovation to maintain a force that is superior to those fielded by potential adversaries. In addition, maintaining an adequate overseas presence, and the ability to conduct peacekeeping and other intervention operations, are essential elements in dealing with new regional dangers.

New Approaches to Long-Term Threats

Challenges to US security are evolving in ways that may also require evolving US military capabilities. The nature of defense planning is changing as well. In particular, slower modernization rates combined with a complex and less predictable threat environment have made longer range planning both more important and more difficult. IDA has developed an analytical approach for conducting long-term planning and tested this approach using a set of case studies.

Our approach compares new military-operational challenges that result from new forms of conflict or emerging strategies for aggression with the capabilities of programmed forces to identify "critical mission areas." Options for improving capabilities in these areas are developed and assessed, identifying implications for programmed forces.

A significant feature of this methodology is the emphasis on "critical missions" rather than, for example, technological or geopolitical threats. Such an approach could help

focus long-range planning during a period of international political change, making it easier to integrate a wide range of disciplines into the planning process, facilitating cross-Service analysis, and ensuring that technological and doctrinal changes are incorporated into new operational concepts.

Confidence- and Security-Building Measures in the Middle East

As events since the September 1993 peace accord between Israel and the Palestine Liberation Organization have graphically demonstrated, confidence and security building will be important components of US security policy in the years ahead. IDA's study of possible arms control measures in the Middle East draws on previous peacemaking efforts in that region and analyzes the European confidence- and security-building process to identify possible parallels.

Our research finds three themes that dominate the current Middle East peace process. First, history shows that confidence- and security-building measures in the region —while neither as formal nor as enduring as those applied in Europe— contributed materially to improving the highly unstable strategic environment there. Second, for a host of strategic, military, and political reasons, confidence-building measures in the Middle East are unlikely to mirror those applied in Europe. Finally, given the complexity of the peacemaking process in the region, future confidence- and security-building measures will rely, at least in part, on the technical expertise of extra-regional powers — the United States, in particular — for monitoring, verification and enforcement. Moreover, formal structural arms control agreements seem unlikely for the foreseeable future.

These themes suggest that the kind of confidence-building measures applied in the Middle East in the past will have to expand in order to build a foundation for more comprehensive peace agreements in the future. Our study identifies a number of alternatives including area surveillance, accounting for treaty-limited equipment, monitoring fixed facilities, technical support for inspecting personnel, and monitoring potential limits on military personnel.

Evolution of the Former Soviet Union

The Former Soviet Union is an area of considerable instability. Growing tensions among the newly independent states may importantly affect Western European security, and in turn US security interests. Understanding the evolving developments in this region, and ways in which the United States might influence these events, remains important.

Cooperative Threat Reduction

Cooperative Threat Reduction (CTR) refers to the activities to stabilize and reduce the residual threat posed by weapons of mass destruction in the republics of the Former Soviet Union. CTR is a $1.2 billion program comprising a variety of projects, from the design of storage facilities for fissile material to the provision of railcars for the safe and secure transport of weapons. Implementation of CTR is often complicated by differing views between the United States and individual republics as to what is in their best interest and by the problems of working with the republics' evolving political and economic systems.

We have conducted an initial examination of several issues important to the success of CTR implementation. Thus far, our analyses have focused on lessons learned from past experiences with technical exchanges between the United States and the Former Soviet Union, and on case studies of two specific programs. These in turn suggest ways to enhance program implementation and streamline the CTR process, both within the United States and between the United States

and former Soviet republics. In addition, IDA's technical expertise is being used to address a number of specific questions, such as the safest and most economical means of disposing of liquid and solid rocket fuel.

Security Concerns in Central Asia

The emergence of independent states in the Former Soviet Union has raised questions about the domestic and foreign policy orientations of these new states, and what this means for Western security interests. In the case of the Central Asian states —Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan — Western analysis has focused primarily on the possible effects of Islamic fundamentalism and the developing rivalry between Turkey and Iran for influence in the region. At the same time, the Russian Federation remains central to all the Central Asian states for economic and security reasons. The ways in which the interests of these external powers are balanced will be an important factor in determining the overall orientation and stability of the Central Asian region.

We have examined the evolving military-security issues in this region. Fundamental to the analysis is the realization that the Central Asian states are separate entities, with separate interests and policies, not a monolithic bloc as often assumed. Indeed, within the region, the competition between Kazakhstan and Uzbekistan to be the leader in Central Asia will be an important factor in shaping the security considerations of each state. More immediately, the civil war in Tajikistan is but one example of the kinds of instability and conflict that might emerge in the future. The Fergana valley in Uzbekistan, with its fertile land and dense multi-ethnic population, is another potential hot spot. Several factors, including the legacy of Soviet economic and ecological devastation in the region, the inability of the Central Asian countries to control flows of people and goods — such as drugs and arms — across borders, and long-standing ethnic and clan rivalries, all contribute to an unstable environment, which could lead to pressures for international peacekeeping and other mediation efforts.

Force and strategy assessments, including those on the Middle East and the Former Soviet Union, reflect the rapidly changing international security environment.

RESOURCE AND SUPPORT ANALYSES

IDA maintains a sophisticated resource analysis capability, motivated by a growing need in DoD for improved visibility and understanding of weapon system costs and schedules, and the factors that drive them. Our program is dedicated to understanding and estimating the resources needed to acquire and operate defense systems and forces. As such, our sponsors have used IDA's research results when making decisions on issues involving force planning, force modernization, and readiness and support. The following examples highlight our achievements in these areas.

Force Planning

Force Cost Modeling

The cost implications of reducing the number of carrier battle groups or increasing the number of Army divisions are examples of relevant questions that can be addressed using force cost models. Force tradeoffs can be analyzed quickly and easily using sophisticated yet flexible, user-friendly models developed by IDA. These models, running on desktop computers, are used by OSD and Service analysts to assist in planning and programming defense resources, and developing the Defense Program Projection. This projection estimates the total DoD budget for 12 years beyond the programming period, given assumptions regarding acquisition and force structure.

Force cost models developed by IDA are based on the information contained in the Future Years Defense Program (FYDP) and align with the structure of the Department's Advanced Mission-Oriented Resource Display (AMORD) model. We help DoD in maintaining consistency between the AMORD model and updates to the FYDP by assigning new program elements to defense mission categories. In addition, we develop rules by which indirect support dollars are allocated to combat forces in the AMORD model.

FYDP Tracking and Analysis System

The Future Years Defense Program, updated three times each year, provides defense analysts with a basis for future projections and serves as the historical record of prior allocations of defense resources. IDA is strengthening DoD's capability to apply FYDP data when conducting planning, programming and budgeting analyses by developing a system of computer-based analytical tools. The FYDP Tracking and Analysis System will record FYDP updates, identify differences from one update to another, and allow easy, efficient comparisons. The utility of this new system will be enhanced through links to IDA's family of force cost models.

Relating Forces to Infrastructure

As budgets fall, DoD managers are challenged to reduce infrastructure spending — in areas such as base operations, training, and recruiting — consistent with force reductions. Before making decisions, managers need to understand the relationships between infrastructure costs and the forces they support. But these relationships are difficult to pin down. To improve this situation, IDA has recommended changing the Department's mission categories so that infrastructure support costs are displayed in a more transparent way. We recommended six infrastructure categories: installation support, force management, logistics, medical support, personnel support, and training. By comparing force levels and spending over the past twenty years, we identified trends in each category — information that is helping DoD predict how program changes will affect infrastructure costs.

Force Modernization

Defense Contractor Costs

Over the past several decades, indirect costs — or "overhead" — have increased dramatically. One major cause has been the replacement of labor by capital. For defense cost analysts, this is a challenging trend since it

introduces increasing error when using traditional methods of estimating the costs of defense systems. IDA is providing greater visibility and understanding of overhead costs through a series of studies and analyses being conducted in cooperation with the largest defense contractors. Our proprietary database of aerospace contractor costs is being updated to include the late 1980s and early 1990s, a period of declining defense spending. In 1994, this unique database will be expanded to include private shipbuilders. These data will support analyses of the cost implications of introducing advanced manufacturing technologies and management systems to increase productivity. Our findings will help identify ways to reduce error in the cost estimates of future systems.

Defense Contractor Responses to Investment Incentives

In the mid-1970s, a DoD study revealed that the ratio of capital to sales for defense contractors was about nine percent, while the same ratio for a control sample of commercial contractors was 20 percent. This divergence was interpreted as evidence that defense contractors were not investing in modern, automated production techniques. In 1977, the Department introduced an incentive, the "facilities capital markup," to encourage automation and increase productivity by defense contractors. DoD has increased this markup dramatically over the years, providing greater incentives. IDA was asked to determine whether these incentives were having the desired effects. Using our contractor database, we found that the ratio of capital to sales has gained parity with the commercial sector.

Spacecraft Cost Estimating

The next generation of spacecraft will be lighter and have higher performance characteristics than do current versions. Because of these trends, traditional weight-based approaches to estimating the costs of spacecraft are not adequate. IDA constructed an improved model for estimating spacecraft development and production costs that includes — in addition to weight — such parameters as power, structural materials content, design life, subsystem performance characteristics, prototyping and the system's mission. The relationships in this model were derived using data from two dozen defense, NASA, and commercial satellite programs. This new method has been applied to estimate the costs of several ballistic missile defense and Air Force satellites, including Brilliant Eyes, the Follow-on Early Warning System and the Defense Support System.

Missile Hardening

In a related study, we developed methods of estimating the cost of hardening spacecraft against the effects of nuclear weapons. We tested relationships that linked costs to the requirements to survive against different types of radiation — X-rays, gamma rays, and neutrons, for example. The resulting method was used to quantify the added cost of hardening several satellite programs, including two defense satellite communications systems, and the Fleet Satellite Communication System. We likewise are developing additional cost-estimating relationships for ground-based missiles that can be used to estimate the costs to harden the Theater High-Altitude Area Defense system.

Aircraft Acquisition Schedules

Acquisition schedules are assessed and sometimes revised during Defense Acquisition Board milestone reviews. Analytical tools provided by IDA increasingly are being used in such assessments. The Air Force F-22 and the Navy F/A-18E/F aircraft programs are two examples.

Our approach to estimating schedule duration parallels our approach to estimating costs. Schedules for acquiring major systems

are driven by program, physical, technical, and performance characteristics, as are costs. Time-estimating relationships are derived for key components of schedules. For example, the length of development test schedules is affected by the rate at which test aircraft can accumulate test sorties and flight test hours.

We have developed models that relate flight-test-sortie and flight-hour rates to aircraft characteristics and the type of test mission flown. OSD used this information when assessing the reasonableness of the F-22 and F/A-18E/F test programs proposed by the Services. In the case of the F-22, proposed sortie and flight-hour rates fell well outside past experience — a factor that led to changes in the program schedule. A similar analysis for the F/A-18E/F showed plans to be in alignment with experience and, as a result, no changes to the flight test schedule were recommended.

Readiness and Support Issues

Cost of Military Medical Care

In fiscal year 1985, medical expenditures accounted for about three percent of the DoD budget. By FY 1992, the figure had grown to over five percent, and the retired military population will increase future expenditures despite the reduction in the active-duty force. Considering this trend, Congress asked DoD to review the military medical care system and survey the members of the Armed Forces and covered beneficiaries.

To assist DoD with this review, IDA is conducting a cost analysis of in-house DoD medical care, including projections of future costs under a variety of policy options. This analysis considers the peacetime costs of the Military Health Services System needed to meet wartime demands, and the costs of DoD's medical care in excess of wartime needs. In addition, we are conducting a survey of military health care beneficiaries. We have designed a survey questionnaire and sampling design. Our survey analysis will address Congressional questions about perceived quality and availability of medical care, and it will serve as a valuable input to framing future policy options.

Logistics Information Systems

To keep complex weapon systems ready for combat, the Services need accurate and timely information on the reliability and maintainability of weapon system components. Such information helps maintenance personnel perform their duties and allows logistics managers to maintain adequate supplies of spare parts. Because of concerns about the responsiveness and accuracy of the Air Force logistics information system for tactical aircraft, known as CAMS/REMIS, IDA was asked to compare the cost and operational effectiveness of that system to an alternative system called TICARRS. Our study measured the effectiveness of each system, identified improvements needed to attain rough parity, and compared the discounted costs to improve and operate each system for ten years. The findings, which favored TICARRS, are seen as an important input to ongoing Air Force, OSD, and Congressional deliberations.

Training Systems

Military managers are being challenged to provide the best quality training possible with available resources. To meet this objective, IDA has been investigating the expansion of interactive training systems. Such systems use computer technology to adjust the difficulty, sequence, content, and style of instruction, thereby reducing the time it takes to reach training objectives and decreasing instructional costs. Results of our studies show that interactive training systems either increase achievement by about 30 percent, or reduce training time by about 30 percent. Either way, the result is a reduction in cost of nearly 40 percent, for a given level of training.

The Institute also is working with the Services and industry to develop technical standards that facilitate portability across hardware platforms, thereby reducing the costs to prepare instructional materials. Further analyses are determining requirements and technical standards for distributed training systems that service geographically dispersed students using video, computer, and networking technologies. These initiatives are helping DoD maintain a ready force.

National Defense Stockpile

The DoD's *1992 Report to Congress on National Defense Stockpile Requirements* called for sweeping reductions in the Government's existing 50-million-ton stockpile of strategic and critical materials, such as cobalt, tin, bauxite, and copper. We played a central role in designing and implementing the process underpinning these recommendations. The process draws together policy inputs from departments and agencies throughout the Federal government, integrates over 70 databases, and uses three interrelated computer models. The recommended reductions, now being implemented, will result in significant savings to the Government — on the order of about $5 billion.

IDA also helped prepare the 1993 Stockpile Report to Congress. This effort involved an intensive review of key planning factors to ensure the estimates reflected the dramatic changes in the national security planning environment. Based on this review and concurrent IDA studies of selected high-technology materials, such as indium, rhenium, and zirconium, substantial additional reductions were recommended to Congress. If implemented, these changes will result in an additional savings of several billion dollars.

DoD Telecommunications

The Defense Information System Agency (DISA) maintains an industrial fund providing resources for the procurement and leasing of information and telecommunication services by the Military Departments and other Federal government customers. IDA develops methodologies for pricing DoD information and telecommunications services under the DISA industrial fund. Our pricing models are constructed to promote efficiency in common-user telecommunications networks and specialized regional voice and data systems. We also developed an automated tool to analyze the competitiveness of existing telecommunications contracts; this enables the Government to identify and take advantage of savings that emerge from the increasingly competitive telecommunications market. In another effort, we are establishing a schedule of user fees to replace existing overhead surcharges, thus permitting service costs to be better allocated to users.

Making extensive use of IDA-developed tools and models, the DISA industrial fund has become one of the more efficient industrial funds within the Defense Business Operating Fund, a business-type financial system encompassing several military industrial and revolving funds. By instilling market economy practices within the fund, DoD is promoting efficient telecommunication and information service use, reducing the costs of providing services, and better allocating its scarce resources.

HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS

IDA is a key component of the National Security Agency's research endeavor. For over 30 years, we have provided cutting-edge research in disciplines fundamental to the NSA mission — particularly mathematics and computer science. Reflecting changes in NSA needs and the state of computing more generally, the structure of the program has evolved into two separate, but interrelated, sets of activities.

Communications Research

The Centers for Communications Research conduct mathematical research vital to the twin tasks facing the cryptologists of the NSA — cryptography and cryptanalysis. Mathematics is the fundamental science used in the creation and analysis of the complex algorithms used to encipher vulnerable communications. As the modes and means of modern communications became more complex, the NSA asked that the Centers expand their research into other areas, to include speech and signals analysis.

As with modern mathematics research groups, the Centers have placed increasing emphasis on computation. Beginning with their acquisition of a CDC 1604 in 1960, CCR researchers have become leaders in anticipating the synergy between pure, theoretical mathematics and the science of computation. In that process, they have developed operating systems, languages, algorithms, and applications software — including, more recently, supercomputing software tools and techniques.

Supercomputing Research

By the mid-1980s, parallel processing was becoming increasingly important. In order to exploit the potential of parallel computing for its needs, the NSA asked IDA to create a Supercomputing Research Center. The Center performs research and development in computational algorithms, operating systems, high-speed networks, programming languages and compilers, and advanced hardware.

As resources grow more constrained, the requirement for high performance computing has been combined with the requirement for more cost-effective solutions. SRC has pioneered the use of some leading-edge technologies to maximize the available computing power per dollar. In doing so, SRC has looked at two sets of issues: making best use of hardware and how best to structure the problem.

Better Use of the System

Some of the extensive computations required for NSA applications can be done more effectively on parallel machines, provided that the power of the parallel architecture is easily available to the user. To make this happen, the memory of the machine should look like a single, very large address space to the user, even though the physical memory may actually be spread over many processors or even over separate workstations connected by very high-speed networks. Toward this end, SRC has several efforts in systems and languages that are directed toward improving the usability of commercial parallel machines, as well as in asynchronous distributed computing to encourage the use of very high-speed networks.

Tailored Algorithms

Because early computers were serial machines, computational methods and algorithms were designed for those machines. When parallel machines became a reality, the initial approach was to parallelize a traditional, serial method. While this is sometimes successful, often it is not. SRC devises new computational methods and algorithms that are based explicitly on the assumption that massively parallel machines will be used and has developed new algorithms in the areas of number theory, discrete optimization, and

linear algebra. Each of the new algorithms produces results that differ significantly from those reached by merely converting methods designed for serial computers.

Contributions

In both the Centers for Communications Research and the Supercomputing Research Center, real world NSA problems are used to motivate research as well as provide a basis for measuring success. As a result, most of the workproduct is classified. However, our efforts, as those of the Defense Department more generally, vitally depend on a vibrant US mathematics and computational science community for talent, for ideas, and for ever-improved computing equipment. Thus, all three of the Centers have forged close ties to their counterparts elsewhere in the scientific community. Ideas and technology flow both ways — from the unclassified world to IDA and from IDA back to industry and academia.

The rest of this section offers examples of IDA technology transfer. The first involves a public workshop in speech recognition chaired by a CCR researcher. The three that follow involve SRC algorithms, tools, and devices that are proving useful to the computational science community at large. We hope that, taken together, they will provide a flavor for the research undertaken at the Centers for Communications Research and the Supercomputing Research Center.

Speech Research: DoD Summer Workshop at Rutgers University

The list of potential applications for automatic speech recognition is very long indeed, including such diverse items as keyboardless computers, automatic dictation/transcription equipment, and operatorless telemarketing. Not surprisingly, the topic is of considerable interest to industry, the Government, and academia.

A CCR researcher chaired an intensive six-week summer workshop involving about two dozen speech researchers from major corporations, research laboratories, universities, the Government, and IDA — as well as many others participating in real time on the Internet. Hosted by the New Jersey Center for Computers in Aid to Industrial Productivity, at Rutgers University, the workshop focused on a public corpus of telephone conversations using the Hidden Markov Model Tool Kit, a commercially available software package implementing speech models of the type first developed at CCR. The workshop applied state-of-the-art speech recognition techniques to the spontaneous speech of the database, with a focus on determining which signal processing techniques were optimal.

In addition to improvements in performance accomplished during that workshop, spin-off effects are anticipated. The participants themselves continue to have access, via the Internet, to the conference computers and software. The workshop record is available via anonymous FTP at ftp.rutgers.edu (directory pub/caipworks) or as a CD-ROM from the National Institute of Science and Technology. A special edition of the *IEEE Journal of Speech and Audio* this Spring will be devoted to workshop issues.

AC: Improving the Usability and Performance of MIMD Computers

AC is a language designed to implement MIMD programming for a class of vector or parallel architectures. It is a modification of ANSI-C that avoids forcing any particular high-level parallel model of computation on the user. One significant advantage of this approach is that AC is used effectively to program high performance subroutines that can be called directly from high-level programming models.

AC's first target is the Thinking Machine Corporation's CM-5. It has been distributed to ten CM-5 sites, including the largest installed

systems at the University of Minnesota and Los Alamos National Laboratory. Several sites are actively participating in testing the compiler and are developing high performance programs using it. Thinking Machines Corporation currently is evaluating AC to understand how it fits in their product line.

Splash 2: Using Advanced Technology to Provide Cost-Effective Solutions

Splash 2, designed and built as an attached processor for workstations, exploits parallelism at several levels. In part, its design was motivated by SRC's earlier work on systolic arrays, but Splash 2 is unusual because its processors are commercially produced Field-Programmable Gate Arrays (FPGAs). FPGAs are semiconductor chips for which users can design or program applications with relatively little effort. Once designed, the FPGAs behave like custom hardware circuitry, hence the high performance. But unlike special-purpose systolic array hardware, the FPGAs can be reprogrammed as often as desired.

Performance on applications programs that are suitable for computation on Splash 2 can equal or exceed that of supercomputers such as the Cray-YMP. For example, on one application — DNA and protein sequence comparison — Splash 2 performance is as good as it is on the best supercomputers available to the community of computational biologists.

In order to transfer its FPGA expertise to US interests outside DoD, SRC is providing access to a Splash 2 system and associated software to researchers at seven different universities. Another system will be delivered to the National Cancer Institute in Frederick, Maryland. SRC also was one of two organizers of the first IEEE Workshop on FPGAs for Custom Computing Machines, a meeting which drew together 125 representatives of research, business, and Government to explore this new development in computing technology.

Parallel Eigensolver: A Novel Approach to a Critical Problem Class

Dense, symmetric eigenvalue problems are prevalent in many applications such as signal processing, structural mechanics, and computational chemistry, including rational drug design. However, despite considerable attention, earlier efforts at parallelizing this important problem class have met with little success.

SRC researchers, in collaborations with colleagues from Argonne National Laboratory, now have developed a parallel implementation of the Invariant Subspace Decomposition Algorithm. Algorithms based on subspace decomposition are a radical departure from traditional numerical methods, in that they make explicit use of the so-called limitations of machine arithmetic in order to obtain a method that is well suited to massive parallelism.

To date, the algorithm has been tested on matrices with uniformly distributed eigenvalues of dimensions up to 6400 and produces extremely accurate results in the form of residuals and orthogonal eigenvectors. Preliminary calculations indicate that the algorithm scales well, achieving speedups on the Intel Touchstone Delta over the sequential version of the algorithm of over 200 on 256 nodes.

AREAS OF SPECIAL INTEREST

While continuing to focus on important issues in areas of long-standing expertise, IDA's research program also evolves in response to the changing needs and priorities of our sponsors. We have chosen here to highlight seven areas of special interest; all received increased research emphasis in 1993. They exemplify our dedication to strengthening and adjusting our research activities to ensure that we continue to fulfill the mission assigned to us by the Secretary of Defense when IDA was established.

ADVANCED SIMULATION

The Institute for Defense Analyses is a leader in developing and exploiting the potential of advanced simulation to address a variety of defense issues. Increasingly, our research has focused on distributed interactive simulation using the IDA Simulation Center. Enabled by advances in computing and communications, distributed simulations are now being used by the Services to improve unit training, complementing more expensive field exercises. These simulations typically incorporate "virtual" environments where battlefield images — complete with terrain features and friendly and enemy forces — are shared among participants. Such distributed simulations allow warfighters at dispersed locations to work and train together, exercising unit combat skills that are otherwise difficult to test in peacetime.

Distributed simulations also offer the potential for improving defense analyses, contributing to assessments of force-wide capabilities, operational concepts, and new weapons and support systems in an infinite variety of conflict situations. Depending on the objectives of the analyses, researchers soon will be able to blend simulation techniques, using mixes of man-in-the-loop simulations and "constructive" models, the more traditional computer-based analytic tools. In some cases, these simulations could be augmented by "live" play from field exercises. The resulting analyses will account for human performance, while retaining the analytic rigor and reproducibility of constructive models. IDA is now examining how these different kinds of simulations can operate together, automatically exchanging data and results, as needed.

Some examples of recent IDA efforts to improve simulation capabilities in DoD and to apply advanced simulation to defense problems are described on the following pages.

Developing and Demonstrating Technologies for Advanced Distributed Simulation

IDA's Simulation Center is a focal point within the Department of Defense for developing and demonstrating technologies related to distributed simulation. In support of the Advanced Research Projects Agency, the Center has conducted numerous demonstrations of distributed simulation capabilities at IDA, as well as at various off-site locations. In concert with ARPA, the Simulation Center also provides technical and analytic support for other Government organizations seeking to utilize distributed simulation. For example, IDA assisted the Army Chief of Staff in establishing his Louisiana Maneuvers initiative, by demonstrating — for the Chief and other senior Army commanders — the potential utility of long-haul networking of Army battle labs. Our staff are active participants in simulation education and outreach activities, such as the Distributed Interactive Simulation Standards Conferences and the annual Interservice/Industry Training, Simulation, and Education Conference.

Some of our ongoing efforts involve evaluating specific simulation technologies. One such technology — referred to as "semi-automated forces" — is particularly important to applying distributed simulation to a wider variety of future training and analytic needs but at higher levels of combat. Because of constraints on the numbers of available simulators and people, large combat engagements often are difficult to conduct using manned simulators alone; semi-automated forces have been developed to expand the numbers of vehicles on the battlefield. These forces are computer-generated and maneuver according to preset rules, under the general control of human commanders. One goal is to have the behavioral characteristics of semi-automated forces appear — from the perspective of the human

participants in the simulation — to be nearly indistinguishable from manned simulators. Another goal is to be able to replicate the behavior of higher echelon forces in the semi-automated forces.

Current semi-automated forces, however, fall short of this goal, and thus IDA has been evaluating various improvement options. In one study, we applied "fuzzy logic" to allow semi-automated tanks to maneuver more realistically to avoid obstacles on the battlefield. And we are involved in testing the integration of a constructive computer wargame with semi-automated forces operating in a virtual environment.

The Synthetic Theater of War Program

In March 1992, ARPA began a program to develop and demonstrate a Synthetic Theater of War (STOW), which would simulate major elements of a theater-level battle — including close combat, combat support, and combat service support — in a distributed interactive simulation environment. Previous simulation exercises have concentrated on close combat, direct fire engagements with a maximum of 1000 entities — such as tanks, soldiers, missiles, and helicopters — on the battlefield, and have focused on troop training. STOW has the goal of demonstrating 10,000 participating entities in 1994 and 100,000 entities by 1997, thus demonstrating the feasibility of using distributed interactive simulation for requirements definition, acquisition, and test and evaluation. STOW also intends to link existing constructive models used by the Services, such as Corps Battle Simulation and Brigade/Battalion Simulation, with live test ranges and with distributed, manned simulations.

The STOW advanced concept technology demonstration will include a number of small exercises and one major exercise. In late 1994, 15 distributed locations will participate in the USAREUR STOW-E exercise and will incorporate virtual and live forces, augmented by a constructive simulation model. Lessons learned from this exercise will be useful in the design and development of technologies for future distributed simulation needs. In 1997, these new capabilities will be demonstrated during a Joint Task Force exercise operating from 50 distributed locations and incorporating limited artificial intelligence capability and dynamic terrain and environmental characteristics. The technologies developed and demonstrated during these exercises will be transferred to the Services by the year 2000 for continued use and development.

IDA's efforts continue to assist ARPA in evaluating technology trends and the technology developments needed for the Synthetic Theater of War program. The Simulation Center is a key element of the technology test beds and demonstrations required for STOW. As part of the test bed, the Simulation Center recently acquired two M1 tank simulators, an M2/3 Bradley, and will soon have a Joint STARS Ground Station Module. Reconfigurable rotary and fixed wing simulators should soon be operational, as well as generic ground vehicles, precision-guided ground-to-air and ground-to-ground weapon systems.

Improving Army National Guard Training

As a result of the Desert Storm experience, DoD identified training deficiencies associated with the roundup and roundout combat brigades in the National Guard. Some problems potentially could be mitigated by the more extensive use of simulation in peacetime training. To assess possible payoffs, ARPA designed an experiment to test the effects of a distributed computer training system in two National Guard brigades. By using such a networked system, units can learn to work as a team while at their home armories — often

separated by hundreds of miles — increasing the opportunities for brigade and battalion staffs to practice synchronization skills.

IDA's key contribution to this experiment is the design of a distributed computer training system based on the Janus combat model. The system is being designed and installed by IDA in the field in several phases. It uses modern Unix workstations and agent software technology, configured to complement other National Guard training programs. The systems for the two brigades incorporate over 300 computers internetted among 15 sites in five states.

Measuring the Value of Distributed Simulation to Training

The United Kingdom is considering whether to procure a distributed interactive simulation system for training purposes. The UK is evaluating the US SIMNET system, the higher fidelity German version of

Manned simulators, such as this M1 tank at IDA, are integral to the Institute's distributed interactive simulation capability.

SIMNET, and other advanced simulator technologies. Because this effort could provide insights useful to US simulation development, DoD has asked IDA to assist in the project, developing analytic tools and methods to be used in the evaluation. Our research focuses on identifying new measures of merit for linking the value of simulation to training and on evaluating data from the UK simulation trials. Part of this effort involves monitoring the UK tests using the trans-Atlantic link of the Defense Simulation Internet at IDA's Simulation Center.

Improving Simulation Planning and Development Processes

We are involved in a variety of efforts aimed at improving the planning, oversight, and development of simulations, DoD-wide. For example, we have examined the role that distributed simulation could play in incorporating the latest design, engineering, manufacturing, and management practices into DoD's acquisition system. Our research suggests that this can best be accomplished by creating a Functionally Integrated System Acquisition process — one that breaks down the traditional "stovepipe," or functional, organizational barriers that inhibit coordination and communication. Distributed simulation, with its focus on interconnecting users and visualizing results, should foster such functional integration. Our work has identified specific investments to promote these ends.

We also have helped DoD develop a strategic plan for advancing the use of synthetic environments, a key science and technology initiative. Working with representatives from all four Services and appropriate Defense Agencies, the Institute provided guidance in outlining the plan and defining key elements including specific technology developments, the overall architecture, and the relationships to the acquisition process and to training needs. Preliminary results have been used by the Services in establishing their science and technology investment plans. We also worked to define advanced technology demonstrations in support of the synthetic environment initiative.

In another project, IDA developed a technical reference model for simulation. This model specifies common reusable services tailored for specific classes of simulations. It is expected that these services will be standardized across different computers, lowering the cost of development and operation of the simulations. The model emphasizes the use of commercial off-the-shelf software that already provides for common functions in a network of computers. The use of such commercial software would reduce the effort of developing distributed simulation entities and refocus the developers' attention on the software specific to each application.

Still another effort involves the distribution and sharing of information on DoD's existing simulations. The modeling and simulation community is widely dispersed, and the related information and data are owned by different organizations at many different locations. The Institute was asked to develop a prototype system for exchanging information on these models and simulations. The resulting system was designed to support distributed ownership and management of data as well as distributed access to data through user friendly interfaces. Tools and applications were chosen from existing and emerging standards common in Internet, so that the modeling and simulation community could take advantage of Internet's current and future work. The prototype system has been transitioned to the Government for operation, and the information system is now available for use by the entire defense modeling and simulation community.

INFORMATION SYSTEMS AND TECHNOLOGIES

The timely and effective use of information is a cornerstone of our strength in both national defense and domestic law enforcement. New computing system architectures, incorporating standardized interfaces to allow rapid integration and interoperability, are improving our ability to fight these information battles. Even before the Persian Gulf War dramatically drove home the importance of information systems integration and interoperability to modern warfare, numerous DoD efforts were addressing these issues.

IDA has assisted the Departments of Defense and Justice in formulating solutions for improving information system integration and information use. We conduct research in such areas as distributed system architectures, computing standards, networked computing operations, wide-area networks and groupware, software reuse, object-oriented technologies, and large-scale intelligent systems.

Distributed Systems Architecture

A well-formed system architecture is key to efficient systems integration and interoperability. This year, IDA assisted DoD in establishing architectural guidance for upgrading and consolidating information systems. These more modern and integrated systems will underpin DoD command, control, communications, computing, and intelligence (C^4I) missions, as well as support functions. We are assisting in the development of DoD's top level technical architecture, pointing the way for C^4I technical migration for the foreseeable future, and the Army Enterprise Strategy vision for similar purposes within the Service context. At a more detailed level, IDA's Force Level C^2 system architecture lays out functional and technical goals for the development of an information system to be used by Joint Task Force Commanders.

The Institute assisted in the technical review of the Goal Security Architecture for the Defense Information Systems Security Program during 1993. This abstract architecture establishes a vision of secure systems and provides a set of security concepts to be incorporated into future DoD information system architectures. And we are assisting in a DoD-wide effort to develop strategies and plans to institutionalize this construct. Among the elements to be coordinated are standards working groups, product vendors and system integrators, acquisition programs, R&D programs, policy and doctrine, education and training, and operational system certification and accreditation.

In the mission support area, we developed the Communications and Security Architecture for the Military Health Services System. The architecture improves the current networking services by upgrading from today's proprietary, dedicated, unprotected networks to the open, secure systems of the future. The accompanying migration strategy lays out a three-phased program to implement this transition.

Computing Standards

Well-formulated standards for system components and interfaces are a key part of achieving integrated, interoperable information systems. For several years, IDA has been developing, maintaining and expanding a detailed survey of standards related to information technology. This "best seller," now in its fourth edition, is used both by information systems planners and architects to learn about the current state and future direction of standards efforts in computing technologies, and by DoD standards personnel in developing guidance for current programs.

In the increasingly important area of computer security, IDA is evaluating technical areas where standards may be required. We are developing new standardized components

for distributed systems security criteria — furthering our previous efforts to replace the DoD Trusted Computer System Evaluation Criteria with "Federal criteria."

We also support the Next Generation Computer Resources Program. Within this area of research, we are helping develop a commercially based family of interface standards for operating systems used in the development and deployment of future Navy mission-critical computing systems. These standards will become available in commercial off-the-shelf products, thus reducing acquisition costs of mission-critical systems. We also are helping select commercially based, database management system standards to meet the Navy's real-time information needs. These standards will be driven by interoperability requirements for ensuring the timely exchange of information among widely dispersed heterogeneous hardware.

Integrated Information Technology Support

To meet increasing demands, DoD must fundamentally redesign the way information services are provided. One option calls for most DoD computers, networks, software, and data to act as a single information resource. We have helped define the principles for an integrated information technology environment, building on commercially proven concepts. Our research team evaluated commercial network management software and implementation alternatives. Key issues included configuration management, maintenance, customer support, security, backup, recovery, system reconfiguration, acquisition, enterprise software licenses, and system development. We then built a model of information technology support for DoD networked computing. IDA continues to assist the Defense Information Systems Agency in developing a concept of operations for integrated information support at network centers and local installations.

Wide-Area Nets and Groupware

More immediate operational needs in DoD networked computing are being met by the Interoperability Decision Support System (IDSS) developed at IDA. IDSS software provides a cost-effective multi-user system for group work across wide-area networks. Functions provided by the generic IDSS software include system security, document coordination, and system management. Organizations easily customize the generic system to their needs by adding programs that run inside the IDSS security shell.

IDSS advanced prototypes have so successfully met immediate needs that they have been fielded as operational systems. Nine on-line multi-user IDSS-based systems are in use by a variety of DoD offices and agencies. One system provides support to the Defense Security Assistance Agency in a range of activities, including training Security Assistance Officers and providing operational support in over 50 countries. Another, the Acquisition Streamlining and Standardization Electronic Transfer System, is under development for use in coordinating writing and editing of DoD standards. IDSS systems also have been used in a distributed network connecting a center in Washington, DC with one at USAREUR in Heidelberg, Germany. Here, IDSS supports US activities required under the Conventional Forces in Europe treaty. Most recently, DoD has been discussing the possibility of licensing IDSS software to industry.

Software Reuse

DoD spends about $30 billion annually for computer software development and maintenance. This high cost underscores the need to reuse software from one application to another, both to reduce software cost and to improve quality. The Defense Information Systems Agency is among those working to

disseminate technology and practices that will increase reuse, and IDA was asked to assess their program. We identified needs for assessments of DoD's reusable software market, technical support of field efforts to accomplish near-term reuse, and experience data on successful reuse projects. Because of a perceived lack of consistent information concerning software reuse practices, DoD also asked IDA to survey several DoD and NASA software projects known to have practiced reuse. Our survey showed that software reuse practices are highly project specific but that reusing software resulted in a higher degree of team productivity and product reliability. Our analysis also determined that NASA could provide valuable assistance to software reuse efforts by developing quality metrics from the software engineering processes that practice reuse.

Object-Oriented Technology

Building software with object-oriented technology offers potential cost savings through better maintainability and reusability. Until recently, most approaches structured software around the functions to be performed. Object-oriented approaches, however, structure software specifications and code around real-world objects, providing a more intuitive basis for software development.

IDA assessed the advantages and disadvantages of this technology compared with traditional software engineering methods. We examined the effects of object-oriented technology on DoD's software development standards, software reuse program, and data administration program. Our conclusions showed that object-oriented technology could improve software maintainability and reuse, but it is not as mature in such areas as database technology. We are currently developing a technology transition strategy and information system usage strategies which will map the use of object-oriented technology to the existing DoD infrastructure of standards, architectures and policies.

Large-Scale Intelligent Systems

The analysis of the vast amounts of complex data collected by Government agencies, particularly those involved with national security, is a far reaching and growing problem. Traditional databases and their associated technology do not offer the means to synthesize data intelligently and rapidly, often depriving investigators and analysts access to critical information. IDA has been designing and developing operational prototype expert systems for the FBI to assist in reasoning about and resolving the increasingly complex issues facing intelligence and law enforcement communities.

Our analysts have worked closely with investigators since 1985, gathering requirements, encoding expert knowledge and testing the effectiveness of the applied research. Rapid prototyping and incremental development have resulted in a series of systems that meet the needs of investigators at all levels of investigation. These systems provide a structured framework for conducting investigations, assisting the investigator in identifying patterns and trends of activity, identifying associations between various objects of interest, quickly gathering background and profile characterizations, and analyzing significant events, travel and movement activity. In addition, the system exploits the communication activities of criminal organizations via a sophisticated telephone usage and pattern detection capability. Results are presented to the user using state-of-the-art graphical techniques, including multi-media and live motion video. Prototype systems are deployed in five sites around the United States and have been employed in high profile cases, including the 1993 World Trade Center bombing in New York.

DUAL-USE TECHNOLOGIES AND MANUFACTURING

The Department of Defense traditionally has been the leader in developing technologies for military applications. Some of these technologies subsequently have been exploited for commercial purposes, but increasingly, the situation is in reverse. This trend is expected to continue, given the nature of technological developments worldwide and the projected reductions in defense spending.

At the same time, DoD is examining how technologies developed for military purposes might be transferred more efficiently into the commercial sector, enhancing the overall economic strength of the United States. Thus, in the future, we may see a freer flow of technologies between defense and commercial uses, with these so-called dual-use technologies becoming more common. IDA is appraising the consequences of such a change, and helping DoD develop technology plans and programs to ensure national security objectives continue to be met.

An area of particular importance is the technology related to manufacturing. To DoD, advanced manufacturing technologies and processes offer prospects for more affordable, high-quality systems produced at the relatively low rates that are expected to typify future acquisition programs. To firms in commercial markets, improved manufacturing capabilities are essential to maintaining competitiveness, both domestic and international. The Government is increasing research funding for manufacturing technologies, and encouraging defense contractors to utilize advanced manufacturing practices and methods.

Because of IDA's expertise in defense technologies and related manufacturing issues, our sponsors have requested increased analytic support in considering ways to improve manufacturing capabilities. The following paragraphs describe recent work in this area and in support of DoD's efforts on dual-use technologies.

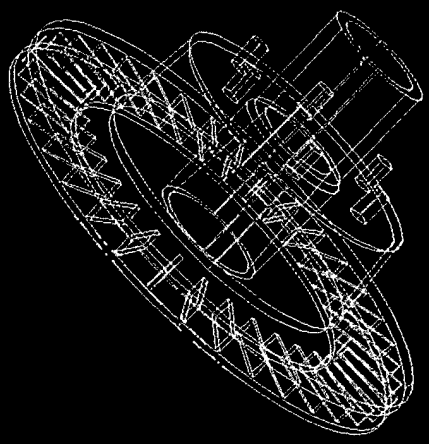
Technology Reinvestment Project

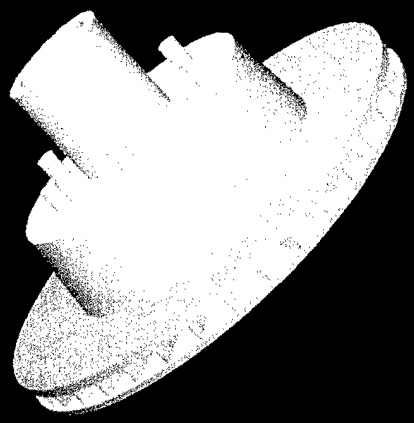
DoD's emphasis on dual-use technology is reflected perhaps most clearly in the Technology Reinvestment Project (TRP). This project fosters the development of dual-use technology and stimulates the integration of the defense and commercial industrial bases into a single national industrial base. More specifically, TRP programs promote the formation of partnerships to advance dual-use technologies, while sharing development costs among the Federal government, state and local governments, and industry. The TRP also supports programs to provide manufacturing and technology assistance to small business, and to develop education and training programs to enhance US manufacturing skills.

The Institute has played a significant role in the development of the Technology Reinvestment Project. We assisted with the initial organization of the Defense Technology Conversion Council, an integrating group formed to manage the TRP. We also helped develop the TRP Program Information Package, the principal source solicitation document. Our efforts addressed regulatory, administrative, institutional, and economic issues, and we provided advice on the economic effects of technology investments. We also assisted in the development of criteria for the selection of proposals, and continue to participate actively in refining the program for future solicitations, currently working with ARPA on an economic analysis of the likely impact of the first set of TRP-funded projects.

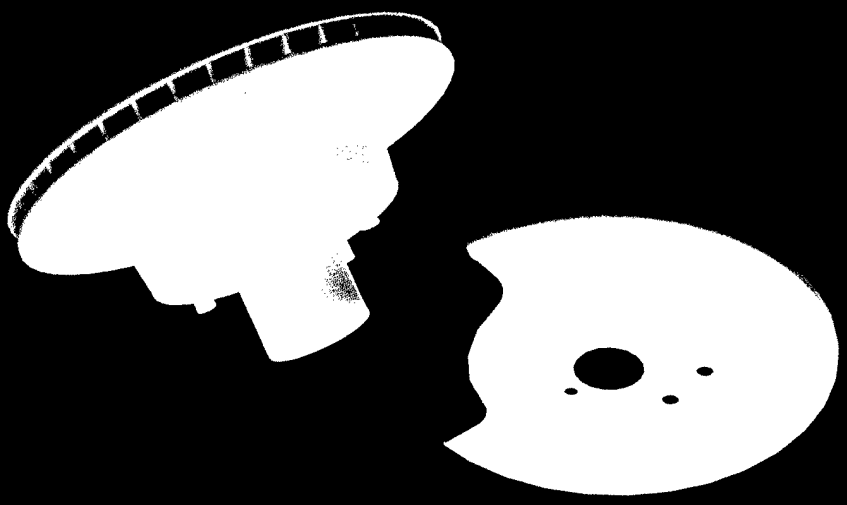
Technology Base Assessment

For several years IDA has assisted the Department of Defense in preparing technology base reports, including the *Critical Technology Plan* and the *DoD Key Technologies Plan*. This year IDA reviewed the Department's technology policies and





Responding to increasing sponsor interest in advanced manufacutring technologies, IDA works on programs to improve capabilities in solid free-form fabrication, a rapid prototyping process using CAD/CAM technology.



programs in 21 technology areas. We examined why these technologies are critical to DoD's mission needs and noted the extent to which the nation is retaining its leadership in each area. In our report, we emphasized the dual-use applications of these critical technologies and the relationship between technology development in the defense and commercial sectors.

Drawing on our extensive technology expertise, a team of more than two dozen IDA analysts worked closely with DoD in completing this task in only a few months. Our analysis showed that about 70 percent of the Department's investment fell in areas that are prime candidates for dual-use applications — information and environmental technologies, materials, and manufacturing. Technology flows between DoD and the commercial sector are extensive, with complex interdependencies. They also vary widely over time and across technology areas. DoD technologies have been adopted for commercial use in the areas of aerospace, materials and sensors. Areas where technology flows have occurred in both directions include communications, computers and software, medical and advanced manufacturing technologies. DoD's support for dual use also is evident in its science and technology policies, many of which are being redirected to emphasize the development of dual-use technologies and cooperative research and development activities with industry and academia.

Engineering and Manufacturing Processes

Experience in commercial industry has shown that integrating the design of products and their manufacturing processes is instrumental in achieving reduced costs. Accordingly, DoD is placing increased attention on engineering and manufacturing processes for weapons systems. To support the Department in these efforts, IDA continues its research on advanced engineering and manufacturing technologies and assists in planning for their development and use.

We have provided technical support to DoD's "Technology for Affordability" initiative since its inception. This initiative is founded in the improvements offered by integrated product and process development; flexible manufacturing systems; computer-aided design, engineering, and manufacturing; and information infrastructures. IDA helped prepare strategies and plans for this initiative and provided technical support for proposed Advanced Technology Demonstrations (ATDs) such as the Flexible Design and Manufacture of Missile/Munitions Seekers. These ATDs are intended to demonstrate the benefits gained from applying advanced manufacturing and information technologies to high-technology products needed by DoD. We analyzed commercially available information systems that may be used in the ATDs, and we will continue to investigate improved information frameworks to support the Department's future design and manufacturing needs.

IDA also supported the Defense Science Board's summer study that put forward a new Defense Manufacturing Strategy. The strategy relies heavily on best commercial practices embodied in such concepts as integrated product and process development, lean manufacturing, and agile manufacturing. Our work included an extensive review of previous studies, technical advice on the application of best commercial practices in the DoD environment, and recommendations for pilot projects and experiments to demonstrate the new approach to defense manufacturing.

Investments in technologies that foster free information exchange help to reduce overhead costs and, in turn, improve manufacturing processes. The Institute has been studying the

extent to which manufacturing companies are investing in information integration, and what key issues are arising. We reviewed the industrial practices of more than 20 companies in three different industrial areas, and documented savings from the use of information-supported integration activities. Our results highlight the benefits of forming information architectures and provide a basis for DoD to move toward an information integration approach with its suppliers.

Manufacturing of Advanced Materials

Research in advanced materials at IDA has addressed several manufacturing issues related to developing advanced materials and incorporating them into high performance hardware. In support of ARPA's Model Factory Program — a program to develop a flexible system for manufacturing fiber-reinforced metal matrix composites — we assessed the costs and benefits of alternative materials, as well as market demand predictions. As a result of our work, the program now includes a broad range of material choices, increasing the potential of developing sufficient markets to support the capital investment for a manufacturing facility.

IDA conducted a detailed review of the materials and structures activity for the National Aerospace Plane (NASP). Our recommendation to move the advanced material selected for the NASP airframe structure out of the laboratory and into a manufacturing environment contributed to the decision to establish a pilot production line for the material.

Another IDA recommendation identified the need for gaining early design and manufacturing experience for an advanced material to be used in missile defense systems. As a result, DoD has initiated an All Composite Experimental Spacecraft Structure Program that will develop advanced manufacturing techniques to produce cost-competitive structures with this new material.

COST AND EFFECTIVENESS OF ACQUISITION PROGRAMS

Cost-effectiveness studies examine alternative approaches for meeting combat and support needs. By providing systematic, quantitative comparisons of the costs and benefits of existing, improved and new systems, these studies help DoD decide which programs to pursue, identifying the key performance features that drive the choices. The so-called Cost and Operational Effectiveness Analyses, or COEAs, are integral to the Department's acquisition process, supporting milestone reviews of major programs.

Building on our expertise in cost-effectiveness studies, IDA was asked by OSD to review several Service- and Agency-sponsored COEAs for thoroughness, objectivity and appropriate analytic methods. Examples of both are highlighted below.

C-17 Transport Aircraft

Rapid inter-theater lift is essential to DoD's ability to provide military and humanitarian assistance world-wide. The amount of lift needed can vary from a few aircraft to a massive airlift of troops and equipment in time-critical cases such as Desert Shield. The Air Force currently is developing the C-17 as a replacement for its aging fleet of C-141 transport aircraft. The C-17 program, however, has experienced growing costs and continuing technical problems. As a result, Congress directed DoD to provide an independent cost and operational effectiveness analysis of the C-17.

At OSD's request, IDA examined a variety of alternatives to the programmed fleet of 120 C-17 aircraft, including restarting the C-5 production line, extending the service life of the C-141s via rewinging, and procuring commercially available freighter aircraft. Alternatives with mixes of several types of aircraft, including ones with smaller numbers of C-17s, were considered and costed. To evaluate the effectiveness of the alternative fleets, IDA estimated cargo flows into selected theaters of interest. The results of our assessment were presented to the Defense Acquisition Board during its review of the C-17 program and served as a key analytic input to the decision process.

Ship-To-Shore Fire Support Systems

Over the last decade, the Navy and Marine Corps have developed new amphibious assault and strike concepts that require the ships of a naval task force to be positioned farther offshore than in the past. This additional distance both enhances task force survivability in the face of increasingly formidable antiship defenses and increases the likelihood that the attack will come as a surprise. However, additional standoff also moves the ships beyond the range of the Navy's existing ship-based gun systems used to support the assault forces. To determine whether recently developed gun, missile, and projectile technologies would enable the Navy to better implement its new concepts, Congress directed that DoD examine the cost effectiveness of alternative ship-to-shore fire support systems.

IDA has identified alternatives that could provide the range, accuracy, lethality, and timeliness needed to attack fire support targets postulated for future combat situations. Because these ship-based systems most likely would be employed in concert with other fire support systems — Navy, Marine Corps, and Air Force tactical aircraft and Marine Corps attack helicopters and artillery — we also have determined the number of ship systems that would be needed to attain desired damage levels, given the contribution of other forces.

The assessment showed the most cost effective, near-term option to be a mix of new projectiles fired from the Navy's 5-inch guns, and a ship-launched version of the Army's Tactical Missile System fired from the

Vertical Launching Systems installed on most of the Navy's cruisers and destroyers. Advanced liquid propellant and electro-thermal-chemical gun systems, with their greater range and payload, offer the promise for further improvements over the next 10 to 15 years.

MILSTAR Polar Adjunct

The Military Strategic-Tactical and Relay (MILSTAR) satellite system provides secure communications for military operations. The originally planned satellite constellation was designed to provide a world-wide communications capability, but funding limitations forced the elimination of the satellites that provided coverage over the Arctic. Because this change affected a number of military missions — Arctic-area submarine operations, transmission of tactical warning and attack assessment data from the US early warning site in Greenland, and various airborne strategic reconnaissance missions — the Air Force initiated the MILSTAR Polar Adjunct program and began a cost and operational effectiveness analysis. The analysis considered alternative communications systems including both dedicated and hosted satellite packages, terrestrial radio systems, and even commercial systems.

OSD asked the Institute to review the COEA. We worked with the Air Force study team to ensure that a comprehensive cost-effectiveness assessment was conducted, with less effort directed toward detailed system designs than was originally planned by the study team. Thus, instead of developing engineering designs to satisfy specific technical requirements, the study focused on how well alternatives could satisfy specific mission capabilities that either cannot be supported currently, or are in danger of becoming infeasible if some existing satellite systems are not replaced. Using this approach, the Air Force team developed a rationale for the acquisition of a Polar Adjunct system that was based on the potential military significance of various missions and the costs of the systems needed to support those missions.

Global Protection Against Limited Strikes

For several years, DoD has pursued a program designed to defend against limited ballistic missile attacks launched by unauthorized individuals within the Former Soviet Union or by developing countries. The proposed Global Protection Against Limited Strikes (GPALS) system comprised space- and ground-based sensors to detect and track the missiles, and weapons to intercept and destroy them before they reach their targets. To help DoD judge which components of the overall system held the most promise, the Strategic Defense Initiative Organization conducted a COEA of candidate GPALS systems. OSD asked IDA to review the COEA, assess the objectivity and completeness of the study, and comment on specific technical issues. Among our recommendations were that the COEA include a broad enough set of analytical excursions to illuminate the conditions under which cost-effectiveness assessments would favor ground-based weapons over space-based ones, and vice-versa. We also suggested a variety of other sensitivity analyses in areas not covered in the initial draft COEA. Most of the recommendations made by IDA were incorporated into the final version of the analysis.

B-1B Conventional Mission Upgrade Program

The Air Force proposes to upgrade the B-1B bomber with new defensive avionics and with a variety of conventional weapons. Before proceeding with the B-1B Conventional Mission Upgrade Program, OSD

directed the Air Force to conduct a Cost and Operational Effectiveness Analysis for the program. Because of our experience in assessing the performance of the B-1B and its defensive avionics system, the Air Force — with OSD's agreement — asked the Institute to conduct the COEA.

We are evaluating a broad range of alternative concepts for upgrading the B-1B's defensive avionics and weapon delivery capabilities. Our study will include a comprehensive technical and operational assessment of the upgrade options, providing estimates of their potential combat effectiveness and cost. The results will be compared to show which systems would provide the most cost-effective upgrades for the B-1B. The overall assessment will be used by the Air Force and OSD in determining whether to proceed with the B-1B upgrade program, and which elements of the program are most critical.

Cooperative Aircraft Identification Systems

The Persian Gulf War highlighted the continued need to ensure that friendly forces are not inadvertently attacked by other friendly forces — so-called fratricide. DoD is concerned that the proliferation of US and European aircraft designs could make future air combat operations increasingly hazardous. In some circumstances, both friend and foe could be flying the same type of aircraft. These circumstances dictate that a reliable Identification-Friend or Foe (IFF) system be in place to identify aircraft. A number of promising alternatives have been proposed, including both cooperative and non-cooperative schemes.

At the request of OSD, we are assisting the Naval Research Laboratory in conducting a COEA of Cooperative Aircraft Identification Systems. The COEA includes comparisons among the existing Mk XII IFF system and a wide variety of proposed alternatives. Although the Mk XII system is old, and newer systems would perform better, it is now installed on such a large number and variety of aircraft that the cost to replace it could be very high. IDA is comparing the advantages and disadvantages of alternatives for aircraft identification in a variety of contingency scenarios, and estimating life-cycle costs.

SUPPORT FOR DoD'S BOTTOM-UP REVIEW

Shortly after taking office, the Clinton Administration initiated a comprehensive review of the nation's defenses. This Bottom-Up Review was conducted to build a multi-year plan for the strategy, force structure, modernization, and supporting industrial base and infrastructure needed in the aftermath of the Cold War.

The modernization portion of the Bottom-Up Review focused on a handful of critical areas in which the Department faced investment decisions that would shape US military capabilities and the industrial base for many years. IDA researchers have been substantially involved in several of these reviews, supporting the Government task groups established to evaluate ongoing programs and technology options. In each case, our expertise was brought to bear very quickly to meet the needs of the task groups. Our contributions to three of the reviews — Army aviation, tactical air forces and space launch systems — are described below.

Army Aviation

Modernizing the Army's helicopter forces is proving costly. Two programs in particular, the RAH-66 Comanche scout/attack helicopter and the Longbow fire control radar and missile, have driven the aviation component of the Army's acquisition budget to record levels.

The Bottom-Up Review examined the merits of these two programs in light of the changing threat and in the context of other options for improving the capabilities of Army aviation forces. The analyses addressed combat effectiveness, cost, and the industrial base implications of alternative modernization plans. The task group responsible for this review asked for our help in assessing several technical areas related to the Comanche and Longbow programs.

Three issues dealt with the Comanche program. The first involved the maturity and technical risks associated with the mission equipment package. Could significant cost savings be achieved, while retaining reasonable effectiveness, by using less sophisticated systems for detecting and acquiring targets and for defensive countermeasures? Our answer was "no." The remaining technical risks appeared modest and previous changes in specifications had already eased technical demands, without sacrificing the most important operational capabilities. Thus, given the advanced state of the Comanche development, significant cost savings could not be achieved by further changing the integrated mission-equipment systems, requiring engineering redesign. Several stand-alone subsystems were identified as candidates for elimination, pending more detailed study of the performance implications.

A second issue concerned the feasibility of installing the Comanche mission equipment package on an existing airframe, thus saving the costs of developing a completely new helicopter. The performance limitations and limited growth capability of the existing airframe argued against this option.

The third issue involved the cost-effectiveness of the Comanche signature reduction program. While the techniques for assessing the combat effectiveness of the program are still being developed, the remaining costs of the current program are expected to be modest enough to make procuring it worthwhile.

In assessing the Longbow program, we identified technical alternatives to Longbow and highlighted the pros and cons of each. We reviewed the technical assumptions underlying the modeling of Longbow's combat effectiveness, and identified the performance specifications that would be especially challenging for the program to meet.

IDA's work was reported to the Government task group on a timely basis, and our analyses were incorporated into the briefing given to the Secretary of Defense, who decided to retain both the Comanche and Longbow programs.

Tactical Aircraft Forces

The FY 1994 defense program called for the development and procurement of four new tactical aircraft — the Air Force's F-22 advanced tactical fighter and Multi-Role Fighter, and the Navy's F/A-18E/F and AF-X. The Bottom-Up Review was focused on whether all these aircraft were needed to meet the changing threat and were affordable within expected budgets.

In support of this review, IDA examined the capabilities and costs of alternative, DoD-wide force mixes of tactical aircraft under a variety of scenarios and conditions. These mixes included the tactical aircraft listed above, plus two conceptual designs for a Joint Advanced Fighter and a Joint Service Stealth Aircraft. The objective of our efforts was to provide quantitative insights on the relative performance and costs of the total force alternatives, the composition of which were specified by the Government task group assigned responsibility for this area.

To carry out this broad appraisal on schedule, we developed a linear programming model to assign aircraft to various missions, depending on the characteristics of the aircraft themselves, weapon capabilities, the threat, and the particular targets. We then obtained performance inputs from the most recent DoD studies, modifying these results to ensure a consistent basis for comparison, and estimated force-wide costs using IDA-developed aircraft pricing models.

Our analyses showed the sensitivity of results to a variety of assumptions about the capabilities and costs of future aircraft, the characteristics of enemy forces, and the depth and hardness of targets. And we identified the implications on combat capabilities over time of developing aircraft in the near term using currently available technologies, or waiting for next generation systems.

Our work was an integral part of the DoD decision process. Numerous sensitivity analyses were conducted to provide insight into issues raised by senior decision makers. Our evaluations, along with budgetary considerations and individual Service needs, weighed importantly in DoD's decision to continue with the F-22 and F/A-18E/F, and to explore new technologies that can be used in the development of common components for future tactical aircraft.

Space Launch

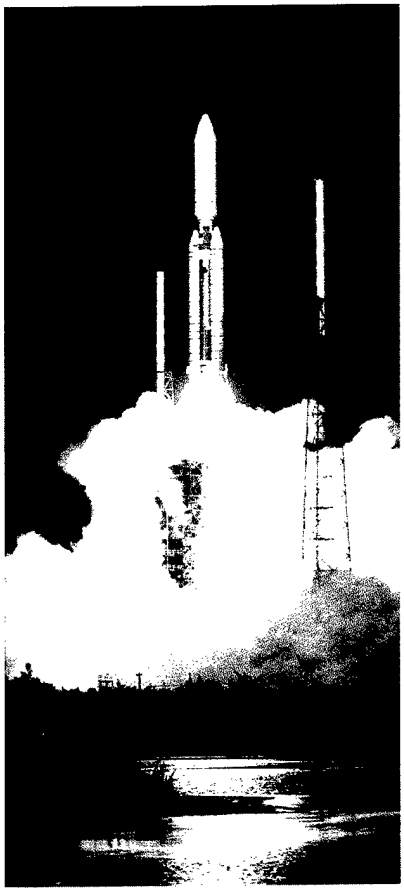
Satellites have played an important role in US warfighting during the last decade, but the launch systems used to put them in orbit are modifications of 1960-vintage ballistic missile designs. These systems are costly, comparatively unreliable and not commercially competitive in international markets. At the same time, a number of programs to develop a new US launch system have been terminated before completion, most recently the National Launch System program in the Fall of 1992.

The Institute supported DoD's review of space launch systems by conducting a rapid, independent analysis of launch requirements, current capabilities, future technology options, and the industrial base. Knowledge gained during previous IDA work for the National Aeronautics and Space Administration served as a basis from which to explore options not previously considered. In particular, a series of meetings with each of the launch system contractors led to the identification of cost-effective options for evolutionary growth of current systems as well as lower risk ways to apply advanced technologies.

This review centered on three principal options for future investment: relying on current launch systems through the use of system and infrastructure upgrades, developing a new "Spacelifter" launch system using current technology, and developing an advanced technology system. A number of advanced technology concepts proved competitive with the Spacelifter option. But the large investment required to develop a new launch system, and the need to include requirements of civil and commercial users as well as those of defense, were the basis for DoD's decision to continue relying on upgrades to the current system.

A number of supporting studies are now under way across the Government to address the future course of launch vehicles from a broad national perspective. IDA is playing an expanded role in this process. We are conducting a study for OSD that will examine the next phase of DoD's space launch road-map. For NASA we are studying cost-effective options for infusing new technology into current expendable launch vehicles, in order to reduce their cost and increase their competitiveness in the international launch market.

TITAN IV



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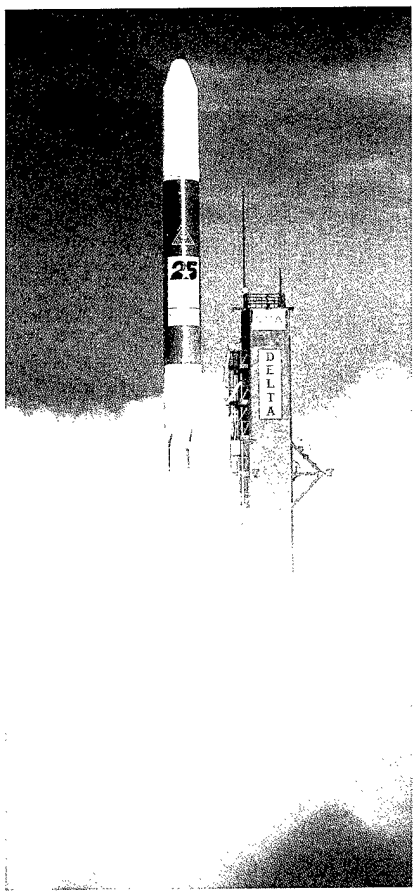
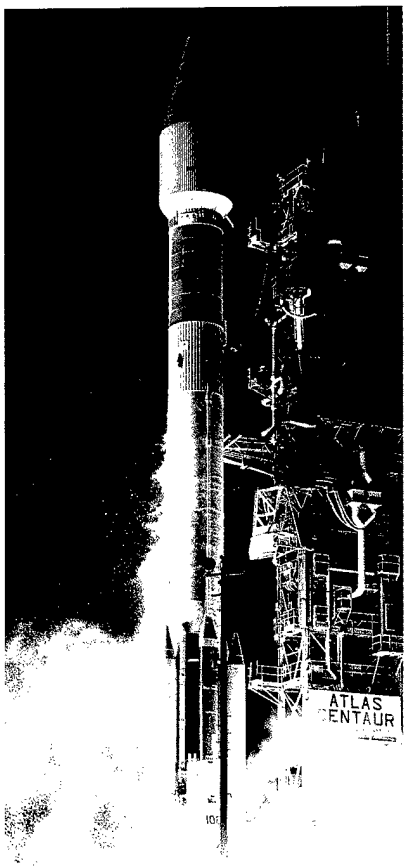


ATLAS



The Institute's support for the Bottom-Up Review included an evaluation of investment options for space launch systems.

ENVIRONMENTAL SECURITY

Growing public concern for environmental issues and the tightening of regulatory requirements have heightened the importance of environmental security to the Department of Defense. The end of the Cold War has accelerated this trend, focusing attention, both in the United States and abroad, on the environmental by-products of decades of superpower competition.

DoD's environmental program has four elements, or "pillars" — cleanup, compliance, conservation, and pollution prevention. Expenditures in all four areas are projected to rise, even as the total defense budget declines. As a result, IDA's sponsors are requesting additional analytic support on environmental security issues.

Since the mid-1960s, IDA has dealt with environmental problems in support of DoD, the National Aeronautics and Space Administration, the Department of Transportation and the Environmental Protection Agency. Much of our early work derived from the Institute's technical strengths in rocket and aircraft propulsion and atmospheric transport. Current studies continue to draw on IDA's expertise in these and other military technologies, such as sensors, materials and manufacturing processes. Additional technical expertise in bioremediation and in other specialized areas is being brought to bear as needed.

Today's environmental work at IDA also calls for a broad base of expertise in defense planning, and in economic, political and resource analysis. The following highlight our current research program and illustrate the diversity of issues under study.

Strategy and R&D Planning

In early 1993, when IDA was asked to support DoD's Bottom-Up Review of the environmental security program, we helped develop an overall strategy and plan for a consolidated technology program. Individual Service efforts were integrated into the "four pillar" environmental program. This construct is now being used in resource and investment planning throughout the defense environmental community.

Building on this effort, the Institute is assisting DoD in developing its comprehensive strategic plan for environmental quality. Covering all Service and Defense Agency programs, the plan is intended to provide a basis for establishing priorities among R&D investments related to environmental security. As a first step, we are helping identify needs for basic research in areas where technological solutions do not exist or are inadequate to deal with the most critical environmental problems. We also are examining approaches for evaluating and setting priorities among disparate environmental activities and programs defense-wide. Throughout the preparation of DoD's plan, IDA will check for consistency with related policies and programs of other Federal agencies.

We helped prepare the most recent DDR&E report to Congress on environmental quality research and development. In addition to describing the overall R&D program and infrastructure, we assessed how well the Services' current technology base programs are meeting DoD's major environmental objectives, and found the ongoing research program to be consistent with DoD environmental priorities, which currently place greatest emphasis on cleanup and compliance.

The Institute has developed a methodology for assessing alternative pollution prevention technologies that could be implemented at Air Force bases. The computer-based model would assist Government personnel in evaluating the relative merits of technology programs based on mission and environmental

impact, cost, return on investment, technology availability, implementation time and regulatory requirements. It also would help in sorting out the complex trade-offs among emerging technologies and off-the-shelf approaches for addressing pollution prevention needs.

Issues Related to Testing

The Office of the Director, Test and Evaluation also has requested IDA analytic support on environmental issues. Test and evaluation facilities comprise more than one-half of the land used by DoD in the continental United States, and the environmental impact of test activities has come under increased scrutiny. For the past three years, IDA has hosted the Annual Major Range and Test Facility Base Environmental Workshop — a forum for the test and evaluation components of all Services and OSD to discuss environmental concerns and to identify common approaches for addressing problems. Topics have included implementation of the National Environmental Policy Act, integration of environmental issues into the test planning process, and the development of strategies for public involvement.

In other test related work, we conducted an assessment of the environmental research and development requirements at major ranges and test facilities, which is forming the basis for the test community's recommendations to DoD's Strategic Environmental Research and Development Program. We have been asked to review environmental laws, regulations and policies to determine the potential effects on major ranges and test facilities, and to assess possible DoD responses. The evaluations have covered issues related to cleanup, compliance, environmental management, and protection of natural and cultural resources.

Technology Assessments

At the most technical level, our experts on sensor systems have examined the possible use of satellite imagery for environmental studies. The materials scientists here worked closely with ARPA on their Supercritical Water Oxidation Pilot Program, which is aimed at developing a new alternative for the disposal of hazardous materials. We also are working with the Army's Environmental Center to evaluate sensor configurations proposed for the unexploded ordnance demonstrations being carried out at the Jefferson Proving Ground. These tests will demonstrate technologies to detect, identify, or remediate buried ordnance — the residue of training and test activities that poses environmental, operational, and safety problems at DoD ranges.

Finally, the Institute is studying alternative uses and disposal methods for liquid rocket propellant being removed from missiles in Ukraine. Our work focuses in part on environmentally acceptable techniques for incineration with or without energy recovery. This research requires an understanding of EPA and other air and water standards, as well as regulations for handling, shipping and destroying hazardous materials. The results of this investigation will be an important element in negotiations with Ukraine, and will be briefed to the Departments of State and Energy, as well as to officials in Ukraine and Russia.

The Institute expects its involvement in domestic and international environmental issues to increase in scope and importance in the next few years, as DoD's efforts in this area accelerate. We recently began an environmental study for the NATO Defense Research Group, Science and Technology Panel, a nine-nation collaborative effort. IDA is directing this US-led, multidisciplinary effort to identify technologies for environmental pollution prevention activities throughout the NATO nations, focusing on clean bases and clean ships.

Using data collected during the Kuwaiti oil fires of 1991 that followed the Persian Gulf War, IDA evaluated existing computer models used to predict atmospheric transport of pollutants from large oil, industrial or urban fires — fires that can adversely affect both the environment and the performance of electro-optical sensors.

TARGET ACQUISITION MODELING

Continually evolving advances in electro-optical sensor systems have provided our fighting forces with a steady improvement in night vision devices and an enhanced ability to acquire and follow targets on the battlefield. On the other hand, current models of human performance in target acquisition do not adequately complement the performance advantages inherent in the new systems. The assessment of these new weapon systems, the development of sophisticated combat simulations, the design of camouflage, and the development of automated target acquisition devices all depend upon the adequacy of our target acquisition models.

IDA researchers play a central role in assessing and improving our basic understanding of the overall target acquisition process. Through our analysis of recent experiments, improved models for detecting and searching for targets have been developed. We continually strive to ensure that appropriate experiments are designed and carried out to support the ongoing model development program and to provide guidance for future procurement decisions of systems in which target acquisition is critical.

Understanding Target Acquisition

Developed over 20 years ago, the first performance models of thermal imaging systems were based on sensors that provided only low resolution images. These models described the target signature as a simple contrast between the target and the background, treating the target as an essentially featureless object. The target's size was approximated by its physical dimension rather than the size of the thermal footprint presented to the observer. Ultimately the thermal model was adapted to visual wavelength imagery, without much change. For simple sensors this approach was adequate. But as thermal imagery resolution began to approach the resolution of visual imagery, the inadequacies of the target acquisition models became obvious.

IDA recently developed an alternate approach to target acquisition modeling that capitalizes on the enhanced resolution capability of modern sensors. This approach basically assumes that target characterization and recognition can be represented by information at a scale finer than the overall size of the target. But incorporating greater detail poses new dilemmas — what information does an observer use to detect a target; what target attributes are essential to the task of recognition? Research using land vehicles indicates that observers do use internal detail within a target when detecting it. Other research shows that observers can recognize targets by discerning simple shapes in characteristic arrangements of important subfeatures — such as the hot spot of the tank track, the relative position of the headlights, or the angle of the turret. This suggests a way to reduce the problem to a manageable set of elementary features. Improved models that are intended to exploit the ongoing experimental research on high resolution target characterization are being developed at IDA.

Although factors such as target size, characteristic features, and contrast variance can be used to broadly characterize the target signature, the background also influences the observer's perception. Buildings, shrubs or trees can clutter up the image, distract the observer, mask the definition of target contours, and obliterate characteristic patterns and textures. None of the simple and traditional measures of target signature has captured the essential interplay between background and target. IDA's current research program is examining ways to account for clutter in the background of visual and thermal scenes, thus leading to a better understanding of how to measure clutter and how to estimate its effect on people acquiring targets.

Time Dependence of Search

A second dimension of target acquisition concerns the process of search, and predicting the time required to acquire a target which, in some circumstances, can be very long even when the probability of static detection is extremely high. Current search models do not yield accurate times required for detection, especially under variable conditions of background clutter and multiple targets.

Our research staff have developed a new approach to modeling the human process of search. We have incorporated this approach into a search model that, for the first time, includes multiple targets and the effect of clutter. The model computes the time to detection based on the attractiveness of the target, as well as the level of distraction provided by background clutter, which the observer sometimes designates as a false target. It incorporates conventional measures of target detectability as well as newer approaches being developed at IDA and elsewhere. This new model represents a critical advance because it will predict the degree to which weapon resources are tied up dealing with false targets. More importantly, it is not computationally difficult and could be introduced into existing combat simulation models with little or no increase in run time.

Analysis of Experiments

The third dimension of target acquisition emphasizes the need for specific types of experimental data for model development and for system procurement decisions. Much of our theoretical work has identified where additional experimental data are needed to support credible implementation of target acquisition models into combat simulations. In one case, we have initiated studies designed to increase understanding of multiple target and multiple observer detection, where correlation among targets and observers is important. In turn, these studies have led to three Army field experiments specifically designed to test the formulations and, ultimately, have resulted in changes to the combat model algorithms for target acquisition. This work also has helped resolve discrepancies in several of the Army's prior field test analyses.

A new set of experiments has been implemented by the Army to help understand the role of specific target types in predicting the detection and recognition process. A set of sensitivity studies using the Janus combat simulation helped IDA prioritize those areas that most needed experimental data to validate model assumptions. Other studies used Janus to evaluate the combat worthiness of an advanced multisensor target acquisition system. One study, using Distributed Interactive Simulation, is examining the feasibility of studying "friendly fire" events which, in part, are caused by the failure of the target acquisition systems.

Other aspects of our work have identified where experimental data were lacking to support system procurement decisions. Armed with better sensors and improved measures of target detectability, the Army and the Air Force have developed systems that automate parts of the target acquisition task. It is widely anticipated that automatic target recognizers will play a major role in reducing the human workload. Early on, IDA promoted the understanding of cueing devices as a tangible first step toward improved automatic target acquisition. Our emphasis on understanding the interaction between the human and computerized cuers led to several Army experiments and further data analysis by IDA. In turn these provided the foundation for understanding the tradeoff between observer performance and the false alarm rate, the central issue in the design of the man/machine interface being developed for the Comanche Helicopter Mission Equipment Package.

IDA's work in target acquisition and search —which combines both original research and the integration of research by others in the community— continues to influence and guide the technical direction of developments in this area.

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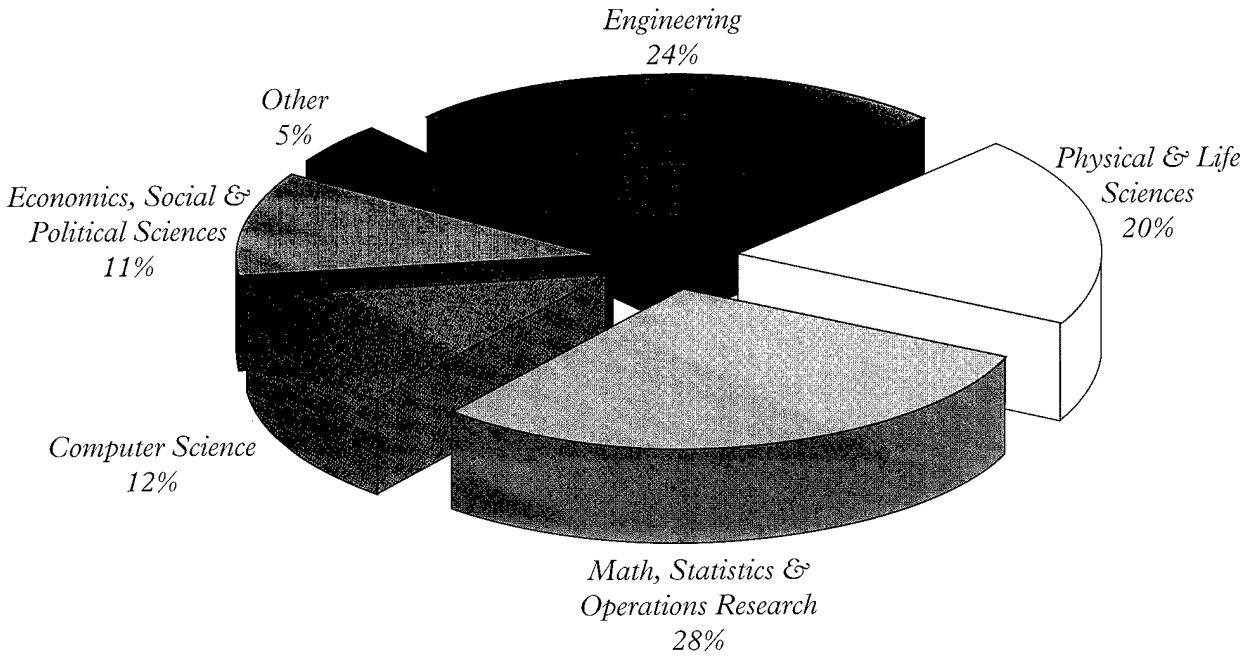
**Term completed March 1993*

STAFF

The men and women of the Institute's research staff represent expertise in a range of academic disciplines from mathematics, engineering, and the physical and analytical sciences to international affairs, economics, human factors and history. To augment this expertise, specialists from universities, industry and other research organizations are called on to contribute their skills as consultants, members of technical panels and working groups, or as staff members on temporary assignment.

As of December 1993, the IDA staff numbered 824, of whom approximately one-half are research staff members. Among the research staff, 62 percent hold doctoral degrees, 29 percent, Masters degrees.



RESEARCH DIVISIONS

IDA is divided into nine research divisions.

Centers for Communications Research-Princeton and La Jolla

Dr. David M. Goldschmidt, Director, CCR-Princeton
Dr. Alfred W. Hales, Director, CCR-La Jolla

The Centers for Communications Research conduct fundamental research supporting the National Security Agency in cryptology, including the creation and analysis of complex encipherment algorithms, as well as speech and signal analyses.

Computer and Software Engineering Division

Dr. Richard J. Ivanetich, Director

The Computer and Software Engineering Division conducts analyses and assesses the application of advanced computing systems and information technologies. The research program also addresses the development of advanced computational techniques and their operational application as prototype systems.

Cost Analysis and Research Division

Dr. Stephen J. Balut, Director

The Cost Analysis and Research Division collects, analyzes and estimates the full life-cycle costs of acquiring and operating forces, systems and components. The division also creates new or improved methodologies and computer-based models for cost estimation, frequently pushing the state of the art.

Operational Evaluation Division

Mr. Thomas P. Christie, Director

The Operational Evaluation Division supports the Office of the Secretary of Defense in the planning and evaluation of Service operational tests of major new weapon systems, and in the observation and evaluation of Live Fire Tests of the lethality and vulnerability of weapons and platforms. The division also supports the Joint Staff and Combatant Commands in the analyses of military operations and in the development, integration and improvement of the mission planning process.

Science and Technology Division

Dr. Lemmuel L. Hill, Director

The Science and Technology Division investigates and models scientific phenomena and conducts technical characterizations and evaluations of devices and systems, the media in which they operate, the targets they engage, and/or the missions they perform. The division also conducts technology assessments critical to research and development programs, acquisition decisions, and technology planning.

Strategy, Forces and Resources Division

Mr. Christopher Jehn, Director

The Strategy, Forces and Resources Division performs integrated, interdisciplinary studies of defense planning and policy related to national security strategy, structure and capabilities of US and foreign forces, and infrastructure supporting US forces. The division develops and maintains specialized tools to execute this research.

Supercomputing Research Center

Dr. Francis Sullivan, Director

The Supercomputing Research Center conducts fundamental research supporting the National Security Agency in various technologies associated with supercomputing and parallel processing, including new architectures, hardware, and software (including prototypes) as well as parallel processing algorithms and applications.

System Evaluation Division

Dr. David L. Randall, Director

The System Evaluation Division analyzes the potential performance and cost of systems proposed or in development, and recommends ways to maximize system performance while minimizing cost.

AWARDS FOR EXCELLENCE

IDA's ability to fulfill its mission depends on the intelligence, expertise and perseverance of its people. To underscore the Institute's dedication to excellence at all levels of the organization, IDA annually presents awards to staff members whose work, either over time or on particular projects, has been exceptional.

The Andrew J. Goodpaster Award for Excellence in Research for 1993 was presented to *Dr. Marta L. Kowalczyk* of the Science and Technology Division. Dr. Kowalczyk's research in target acquisition and search performance modeling is widely recognized in the modeling community, both nationally and internationally. Her work has placed IDA at the core of the target acquisition model improvement programs, combining critical analysis of current models with a collaborative role in developing improved models. She has initiated original work in modeling the target acquisition performance of multiple observers and multiple targets, and in the development of clutter metrics in infrared imagery. Most recently, Dr. Kowalczyk extended her research program to the modeling of low observable targets.

The W. Y. Smith Award for Excellence, designed to recognize outstanding contributions by non-research professionals, went to *Ms. Sharon L. Stiles* of the Personnel Directorate. Ms. Stiles is responsible for administering the Institute's compensation and benefit programs, and for communicating those programs to IDA's management and staff. Distinguished performance — in both the quantity and quality of work — and dedication to service have earned her this award.

The IDA President's Award for Excellence was established to recognize and reward support staff members who have made significant contributions to the Institute's success. This year, awards were presented to *Mr. Nathan P. Douglas* of Administrative Services and *Ms. Rose Mary Ferguson*, Operational Evaluation Division. Mr. Douglas was honored for his long-term commitment to excellence as a Services Assistant, providing conference services and other support functions. Ms. Ferguson received the President's Award for her outstanding performance and impressive record of accomplishment as Senior Staff Secretary.

The 1993 Awards for Excellence were presented to, from left, Nathan P. Douglas, Sharon L. Stiles, Marta L. Kowalczyk, and Rose Mary Ferguson. These annual awards honor staff members for exceptional contributions to the Insitute's mission.

IDA makes every effort to ensure that our staff is aware of important political and analytical developments, and that our work is well-grounded in reality. In addition, we strive to share our analytical tools and insights with the broader community both within and outside of government. Toward these ends, the Institute has developed a rich program of outreach activities.

Colloquia and Symposia

IDA Speakers Program

In addition to technical seminars held by the individual research divisions, IDA hosted a rich diversity of outside speakers. A sampling of our guests, with their affiliation at the time of the presentation, illustrates the breadth of issues and perspectives represented.

E. C. "Pete" Aldridge, Jr., President and Chief Executive Officer, Aerospace Corporation
The Future Direction of the US Space Program (Stovepipes, Space Launch, and International Cooperation)

David J. Berteau, Principal Deputy Assistant Secretary of Defense, Production and Logistics and Chairman of the Defense Conversion Commission
Defense Conversion

D. Allen Bromley, Sterling Professor of the Sciences, Yale University
Science and Technology Policy in a Rapidly Changing World

Leslie L. Byrne, Representative, 11th District of Virginia, U.S. House of Representatives
Defense Conversion

Robert Mullan Cook-Deegan, Director of Biobehavioral Science and Mental Disorders Institute of Medicine, National Academy of Sciences
The Human Genome Project: History and Prospects

Eliot A. Cohen, Director, United States Air Force Gulf War Air Power Survey and Professor of Strategic Studies, Paul H. Nitze School of Advanced International Studies, Johns Hopkins University
Gulf War Air Power Survey

Seymour Cray, Cray Computer Corporation
Massively Parallel Computing

Malcolm R. Currie, Chairman Emeritus, Hughes Aircraft Company
Defense Conversion — Fact and Fantasy (A View from California)

Edward E. David, Jr., President, EED Incorporated
Technology and Competitiveness

Alexander Flax, National Academy of Engineering
Pathways of Military R&D in Peace and War

John S. Foster, Jr., Board of Directors, TRW Incorporated
New Challenges and Directions for US Technology Policy

Frederick M. Franks, Jr., General, USA
TRADOC: A New Strategic Context for the Future

Donald Freedman, Executive Secretary, DoD Advisory Panel on Streamlining and Codifying Acquisition Laws
Streamlining US Acquisition Law

James E. Goodby, US Negotiator on Safe and Secure Dismantlement
Dismantlement of Nuclear Weapons in the Former Soviet Union: Progress and Prospects

Christopher Jehn, Senior Fellow, Institute for Defense Analyses, formerly Assistant Secretary of Defense for Force Management and Personnel
What I Learned in the Pentagon

Sergei Karaganov, Deputy Director of the Institute of Europe and member of President Boris Yeltsin's Presidential Council
Russian Defense Policy

George (Jay) Keyworth, II, Chairman, The Keyworth Company,
The National Science and Technology Agenda

William J. Lynn, III, Director, Program Analysis and Evaluation, Office of the Secretary of Defense
DoD Bottom-Up Review of Defense Needs and Programs

Donald A. Mahley, Deputy Assistant Director, Bureau of Multilateral Affairs, US Arms Control and Disarmament Agency
Chemical and Biological Weapons

Judith Morehouse, Director of Government Business Relations, Boeing Company, Vice President of Boeing International Corporation
Reforming DoD Procurement: Overcoming Barriers to Acquisition of Commercial Products

William J. O'Neil, Galileo Project Manager, Jet Propulsion Laboratory
The Galileo Project: Detour to Jupiter

James T. Thurman, Supervisory Special Agent, Explosives Unit, FBI Laboratory
Forensic Investigation of Pan Am 13

Vitaly Zhuravsky, President of the Christian Democratic Party of Ukraine
The Political Environment in Ukraine

IDA Cost Research Symposium

DoD has nurtured a diversified program of cost research for several decades. The first catalogs of cost research projects were published by the Cost Analysis Improvement Group (CAIG) in 1978 and 1983. IDA extended the practice in 1987 with publication of a cost research compendium, and again in 1989 with publication of a more extensive catalog. The catalog provides information that facilitates exchange of findings, data, and plans. This flow of information has helped avoid wasteful duplication of effort, made research planning decisions more informed, and encouraged joint sponsorship of research on topics of common interest.

In 1989, IDA also held its first annual cost research symposium, attended by directors and senior staff from DoD offices most involved in the conduct of cost research. The CAIG, an active participant, began in 1992 to exploit the symposia to develop annual DoD Six-Year Cost Research Plans. The plan and symposium are now principal elements of an annual process for formulating DoD's research program and publicizing its findings. Through the symposium, the cost research community is informed of the current status, achievements, and perspectives emerging from the cost research program. The plan builds on this foundation, describing an intellectual framework to guide future research. Through this relationship the CAIG Chairman has become a joint sponsor and source of support for this important outreach program.

Education Programs

Recognizing the interdependence between academic science and national security, IDA has designed a number of programs to attract talented young scientists to national security issues and to enrich the curriculum in the field.

The Defense Science Study Group (DSSG)

The DSSG, founded in 1985, is a program of education and study for young professors of science and engineering who have achieved national recognition in their fields. Directed by IDA and sponsored by the Advanced Research Projects Agency, the program helps foster a long-term, informed interest in national security issues among the new generation of leaders in science and technology.

Over a two-year period, the 15 members spend 20 days each year focusing on national security policy, related research and development, and the systems, missions and operations of the armed forces. As part of the second year of the program, members conduct individual or group study projects on important national security problems. The 1992-1993 DSSG class, which held its final session in November, completed studies on subjects ranging from torpedo defense and radar wave propagation, to nuclear waste disposal and the applicability of military training techniques to the civilian sector. Three studies are highlighted below.

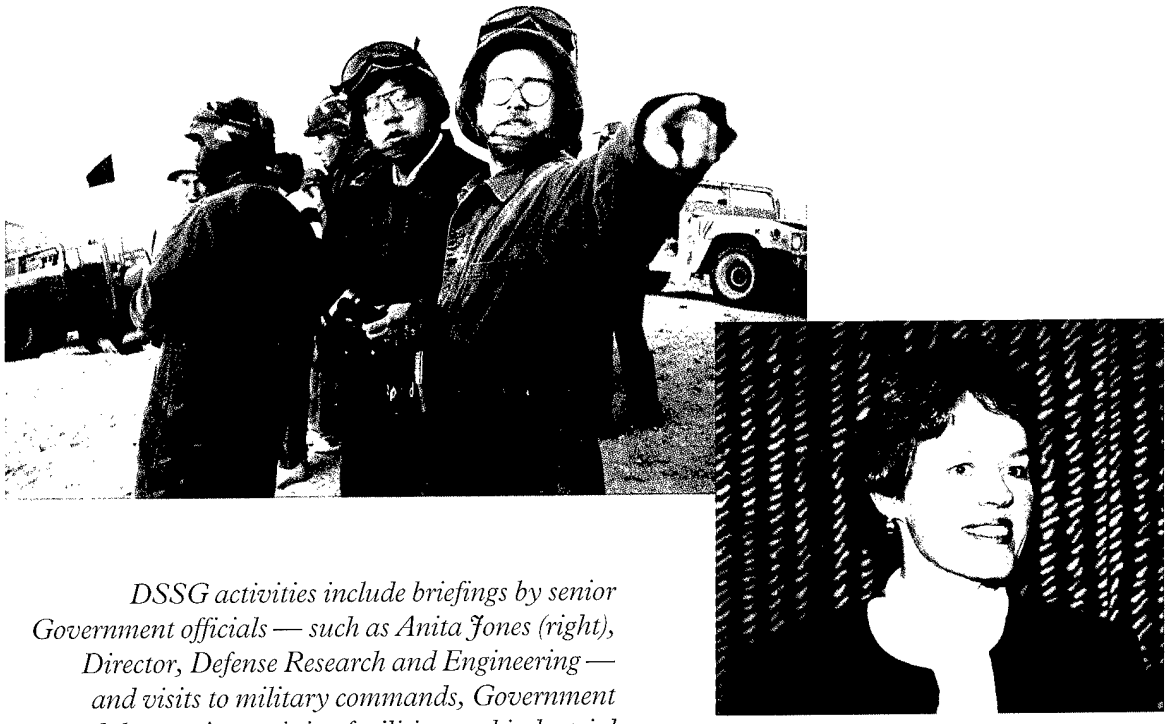
Fatigue Monitoring. When is the best time to replace critical aircraft components such as rotor blades on helicopters? This problem is becoming increasingly important as budgetary pressures are sharply limiting military modernization programs. A new approach, suggested by a DSSG member, takes advantage of recent progress in silicon-based microsensors. Sensors, imbedded in the component itself, could use a combination of sensing techniques channeled to a central on-board computer to provide continuous, real-time monitoring of fatigue cracking. If successful, such a system could lead to both reduced maintenance costs and increased crew safety.

Airport Security against Bomb Threats. In order to be effective, an airport security system must reliably detect explosives, yet be affordable and relatively unobtrusive. Two DSSG

members, a chemist and chemical engineer, collaborated on a proposed system designed to counter the challenging threat posed by non-metallic explosive devices. The system would be comprised of a number of sensors for detecting chemicals that are characteristic of explosives: a vapor detection system for direct application to passengers, an X-ray system for carry-on luggage, and a system using a combination of X-rays and neutron activation analysis for checked baggage.

Identification, Friend or Foe (IFF). A disproportionate share of allied losses in Operation Desert Storm were due to "friendly fire" — a battlefield problem of long standing. An effective IFF system must enable the attacker to distinguish friend from foe without significantly increasing either its own vulnerability or that of other friendly forces. Three DSSG members examined this problem and proposed two possible solutions. The first is based on the use of spectrally-encoded bar codes similar to ones used in supermarket checkout counters. Using this approach, the attacker could quickly probe a target looking for a secure return, while the target remained passive. In the second approach, high-speed electronic switches can enable potential friendly targets to selectively reflect a friendly attacker's encoded probe but not the transmission from a hostile sensor.

The DSSG program is an investment in the future. IDA and ARPA make every effort to ensure that alumni have opportunities for



DSSG activities include briefings by senior Government officials — such as Anita Jones (right), Director, Defense Research and Engineering — and visits to military commands, Government laboratories, training facilities, and industrial organizations. Above, DSSG members visit the National Training Center at Fort Irwin.

continued involvement with national security. A number of program alumni are now participating as members of the Defense Science Board and JASON, a group of academic science advisors; others are serving as consultants to organizations within the national security community, and one alumnus is currently spending a sabbatical at ARPA.

SRC Special Summer Internship Program

At its Bowie, Maryland facility, the Supercomputing Research Center sponsors a summer internship program to introduce talented young students to the challenging problems of parallel processing. Although most of the two dozen participants are university computer science majors, SRC also participates in the Westinghouse Science Talent Search program to attract a handful of truly outstanding high school students. A small number of students work on classified projects, while the majority have worked on unclassified projects such as designing new tools for the CM-5, implementing algorithms used to find optimal computer networks, and designing new algorithms to run on SRC's own Terasys machine.

Cost Analysis Education

For the past several years, IDA has shared its expertise by conducting a graduate level course in cost analysis. This course, offered annually in cooperation with George Mason University, focuses on the every day problems of defense cost analyses and effective methods for dealing with them. IDA staff members, who are expert at estimating the acquisition costs and schedules of defense systems, provide evening lectures on these and other topics, including force costing, risk and uncertainty, learning and production rate effects, and cost-effectiveness analysis. Each year, the course content, lectures, and materials are updated and improved to reflect new developments in cost analysis research.

FINANCIAL REPORT

BALANCE SHEETS

September 24, 1993 and September 25, 1992

Assets	1993	1992
Current assets:		
Cash	$ 809,239	$ 897,737
Investments	12,424,352	9,704,952
Contract receivables	12,321,300	15,035,540
Prepaid expenses	572,232	317,620
Total current assets	26,127,123	25,955,849
Bond issue costs - net	649,192	421,329
Prepaid ground rent, less current portion	1,133,600	1,155,400
Property, plant and equipment - net	26,328,118	26,514,220
Other assets	71,999	21,499
Total assets	$54,310,032	$54,068,297

Liabilities

Current liabilities:		
Current portion of long-term debt	$ 798,611	$ 1,193,325
Accounts payable and accrued expenses	6,535,813	6,094,670
Accrued annual leave	3,488,776	3,456,031
Accrued pension costs	195,454	189,046
Total current liabilities	11,018,654	10,933,072
Long-term debt, less current portion	12,193,931	12,969,098
Commitments and contingencies		

Corporate Equity

Corporate Equity	31,097,447	30,166,127
Total liabilities and corporate equity	$54,310,032	$54,068,297

The Institute's audited financial statements are available from the Treasurer on request.

STATEMENTS OF REVENUE AND EXPENSES AND CHANGE IN CORPORATE EQUITY

for the years ended September 24, 1993 and September 25, 1992

	1993	1992
Revenue:		
Contract revenue, including fixed fees of $4,911,045 and $5,136,560, respectively	$105,109,217	$99,924,842
Program expenses:		
Charged to US Government contracts:		
Direct salaries	47,853,384	44,752,831
Other direct costs	30,166,894	26,299,993
Indirect costs	23,412,736	23,735,458
	101,433,014	94,788,282
Charged to Institute projects:		
Direct salaries	576,489	518,966
Other direct costs	1,364,348	971,796
Indirect costs	1,140,560	1,040,725
	3,081,397	2,531,487
Total program expenses	104,514,411	97,319,769
	594,806	2,605,073
Interest income	336,514	166,226
Bond arbitrage rebate	-	(199,800)
	336,514	(33,574)
Excess of revenue over program expenses	931,320	2,571,499
Corporate equity:		
Beginning of year	30,166,127	27,594,628
End of year	$31,097,447	$30,166,127

The Institute's audited financial statements are available from the Treasurer on request.

SPONSORS

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