

REPORT OF THE DEFENSE SCIENCE BOARD TASK FORCE ON TECHNOLOGY BASE STRATEGY.

 October 1976

Office of the Director of Defense Research and Engineering
Washington, D.C. 20301

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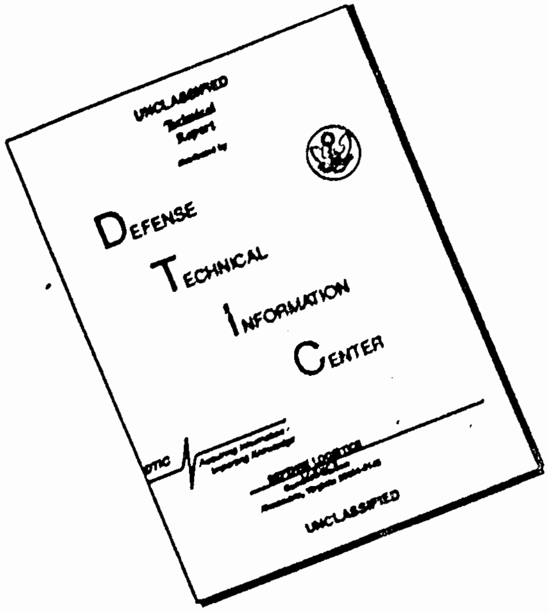

DEFENSE SCIENCE BOARD

REPORT OF THE TASK FORCE

ON

TECHNOLOGY BASE STRATEGY

OCTOBER 1976

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

September 15, 1976

TO: THE SECRETARY OF DEFENSE

THROUGH: DIRECTOR OF DEFENSE RESEARCH & ENGINEERING

The attached report of the Defense Science Board Task Force on Technology Base Strategy was prepared at the request of the Director of Defense Research and Engineering. The Task Force, under the direction of Dr. Norman Rasmussen, was chosen to include members from industry, medicine, government, and universities with a broad range of technology experience.

In the Preface, Dr. Rasmussen states the expectation of the Task Force that the report will serve as a useful basis for discussion between the Office of the Director of Defense Research and Engineering and Military Department managers of the Defense Technology Base. In the belief that the report will meet that objective, it is hereby submitted. The recommendations of the Task Force are summarized in the section entitled "Summary Statement".

Solomon J. Buchsbaum
Chairman
Defense Science Board

Attachment

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PREFACE

The Department of Defense will be expending over $1.8B in FY 1976 in support of a Defense Technology Base. The base spans nearly the entire spectrum of science and engineering and supports research and exploratory work in areas directly pertinent to military defense. Because of the breadth of scope and the research nature of the effort, it is often difficult to know where to place priorities in the Technology Base. Because of the many organizations involved in Technology Base implementation, management is complicated and performance level and impact are difficult to assess. Yet these tasks (prioritization and assessment) must be done and done well, for on the Defense Technology Base rides the nation's future military capability.

In May 1975 the Director of Defense Research and Engineering asked for an independent assessment of the DoD's investment in defense technology. Specifically, he requested the Defense Science Board to form a Task Force to provide expert opinion and advice on the allocation of Technology Base resources among various technology management areas. Guidance is particularly needed in identifying those technical areas in which the level of support should be adjusted as a result of: (1) Changing DoD needs; (2) Changes in industrial and university R&D capabilities; and (3) Maturation of technical areas with the consequences that few significant further advances are probable.

In August 1975, following a number of preliminary meetings, the Task Force on Technology Base Strategy met in continuous session for a two-week period at the Naval War College, Newport, Rhode Island. The conclusions resulting from the review and discussion sessions at Newport are the basis of this report.

The report begins with a Summary Statement which explains how the Task Force carried out its assignment, what it used as its data base, and what it found as its principal conclusions.

Although not specifically requested in its charter, the Task Force also gave consideration to a few non-technical aspects of the Defense Technology Base - issues involving management, prioritization, and innovation in defense technology. Although tending to be somewhat philosophic in nature, these are aspects which influence the potential success of the investment in Defense Technology Base activities. The views held in common by most members of the Task Force on these subjects are collected in a section which follows the Summary Statement.

For the reader desiring amplification of the Task Force's principal conclusions, and more detailed comments on the various technology areas comprising the base, the report concludes with three technical Statements which address these subjects.

Finally, the Task Force would conclude this Preface by stating its view of the usefulness of this report. The report records the perceptions of a group of scientists and engineers, trained in a diversity of disciplines and quite variable in first-hand knowledge of DoD research and technology activities. The Task Force hopes the report will serve as a useful basis of discussion between ODDR&E and Military Department managers of the Defense Technology Base. More than this is difficult to assess. Certainly, it would be presumptuous of the Task Force to expect its recommendations from a two-week review to be followed in detail, and unrealistic for defense managers to expect to find the panacea for their problems within the body of this report.

The Task Force would like to emphasize the limitations of this study. Following the terms of reference, the Task Force for the most part limited its review to the way funds are currently being allocated. No in-depth study was made of either the efficiency or effectiveness of the program management or the research organization. Although some observations of the Task Force on these matters are recorded, no attempt has been made to make a critical study of these matters.

1. Summary Statement

1.1 Task Force Objectives and Organization

The purpose of the Task Force on Technology Base Strategy was to provide DDR&E with an independent assessment on how well funding resources were allocated among the many technical areas of the base. The Task Force looked specifically for areas where it would seem appropriate to increase or decrease current allocations, and areas where there appeared to be opportunities for focus or integration to obtain a better return on the current investment.

In undertaking its work, The Task Force divided into three panels, each covering a number of technical program areas. The panels were:

- Panel on Environmental and Life Sciences - covering programs in biomedical, environmental (atmospheric science, oceanography, etc.), and behavioral science, as well as programs in chemical/biological defense and peacetime environmental quality (control of pollutants).

- Panel on Electronics - covering mainly programs on the defense applications of electronics.

- Panel on Engineering Technology - covering engineering-oriented programs in missile and aircraft propulsion, military vehicles, conventional weapon technology, and materials and structures science and technology.

These areas of division were selected because they correspond to management areas under Assistant Directors in the office of the Deputy Director (Research and Advanced Technology), the cognizant OSD office for Military Department Technology Base activities. During the course of the study, the panels met in briefing and discussion sessions with corresponding Assistant Directors and their staffs, and with appropriate Military Department representatives. The Task Force as a whole had briefing and discussion sessions with the Assistant Secretaries (R&D) and other senior Technology Base management officials of the Military Departments and with the Director of DARPA. The Task Force was also provided access** to the Technology Coordinating Papers (TCPs)*, Executive Analyses** of the TCPs, and other documentation pertinent to the Technology Base. The briefings and documentation just described represented the main elements of input to the Task Force.

1.2 General Comments on the Technology Base

In addition to its technical review, the Task Force spent some discussion time on general features of the Technology Base. The Task Force noted as strengths:

- The recognition of the Technology Base as an important defense activity by DoD management.
- Continued payoff from the Technology Base efforts. This observation is particularly apparent if one looks at improvements obtained over a 10 or 20 year period where yearly incremental advances are accumulated (e.g., increases in thrust to weight for jet engines of factors of 2-3; reduction in battlefield mortality for wounded personnel by a factor of 2, etc.).
- The presence in the total base of a quick-action, high risk, high-payoff technology operation. The Task Force is referring to DARPA's role in the Technology Base.
- Reasonable allocation levels for the broad scientific and technology areas comprising the base. The Task Force could not find any solid arguments for gross changes in these levels, but did see a need to evaluate these levels by more penetrating analyses of impact and cost effectiveness.

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* The TCPs are documents, 50 to several hundred pages in length, which summarize and to some extent justify and prioritize all on-going DoD endeavor in specific science or technology areas. The areas covered by TCPs are shown in Table III. TCPs are written jointly by the three Military Departments under the coordination of ODDR&E.

** Executive Analyses are ODDR&E staff assessments of the strengths and weaknesses of the technical areas covered by the TCPs.

The Task Force discussed a number of problem areas, all of long standing and all noted by previous reviewers of the Technology Base. Among these might be cited:

- The complicated and layered nature of the management structure over the DoD in-house laboratories. Since the in-house laboratories implement over 40% of all Technology Base endeavor, the degree to which the management structure adversely affects the quality of implementation is an item of concern.

- The inertia to change, stemming in part from the management structure. Over a period of time, this has the effect of protecting and supporting investment in low priority endeavor rather than encouraging orderly shifts to new areas of higher potential and payoff.

- The fragmentation of fields of endeavor between many different organizational units.

- The tendency of the Technology Base to be isolated from the system developer and the operational forces. The possible contributions of Technology Base implementers to problems faced by personnel in the field and to new systems under development are thereby lessened. The tendency towards such isolation is not uniquely the fault of implementing Technology Base organizations.

The problems above, as previously noted, are long standing. The Task Force observed some new DoD efforts, in execution or planned, to help ameliorate some of these difficulties. The Task Force commends:

- Selective use of block funding to laboratory technical management for Technology Base activities.

- Increased contract to in-house ratio for Technology Base activities.

- Army reorganization plans to set up integrated Development Centers which will include laboratory Technology Base activities.

- Studies such as the Navy "Strike-Warfare Exercise" and the Air Force "Technology Base Investment Strategy Exercise" which are efforts to assess better the impact and cost effectiveness of investment in specific areas of the Technology Base.

1.3 Opportunities for Funding Increases

Each of the technical panels examined their specific technology fields for areas where increased investment appears warranted. We have termed these areas "opportunities for funding increases." In line with DDR&E instructions, however, we have balanced these increases with an equivalent dollar value of decreases (discussed in section 1.4).

In the listing below, we summarize what we believe are the more significant recommendations for increased funding. Fuller details and additional items are included in section 2.

- Training R&D - a large payoff should accrue from application of new training techniques, particularly simulators, to a broad spectrum of military training problems.

- Software Cost Reduction - a national problem, but of particular importance to the DoD.

- Gas Turbine Development - of great DoD importance because of spiraling fuel costs.

- Environmental Factors Affecting Weapons System Performance - with particular emphasis on the detailed meteorology of small tactical areas and on oceanography pertinent to ASW problems.

- C^3 for Tactical Field Commanders - a serious operational problem to which technology can contribute.

- Digital Controls for Power Plants - to provide not only for improved performance, but for improved maintenance and repair avoidance as well.

- Peacetime Environmental Quality - to assure DoD input standard setting and DoD conformance at acceptable cost.

- o **Adaptive Acoustic Arrays** - for improved undersea target detection techniques.

- o **Substitutes for Critical Materials** - to lessen impact on future DoD operations of shortages in critical materials.

1.4 Opportunities for Funding Decreases

To balance the increased funding recommended in the previous section, the panels recommended decreased funding in a number of areas. Summarized below are the more significant of these recommendations. Fuller details and additional items are included in the unpublished, back-up documents entitled "Reports by the Panels."

- o Surface Effect Ships - until the possible mission is better understood, the investment appears disproportionately high.

- o RF Electronic Systems - a better focused program should cost less than current expenditure.

- o Special Computers and LSI - greater reliance on industrial capability is possible although some special DoD applications must continue.

- o Personnel Classification, Selection and Assignment - an important area, but a lower Technology Base investment should be sufficient.

- o Advanced Fighter Technology Integration - Air Force concept as understood by Task Force does not appear viable. Less expensive adaptations of existing aircraft platforms may provide the vehicle needed for technology evaluation.

1.5 Opportunities for Integration and Focus

Areas where the funding level seemed reasonably appropriate, but where there seemed to be excessive fragmentation or lack of direction were noted by the panels. These areas, termed as "opportunities for integration and focus," represent areas where better return on the investment seems possible. Summarized below are the more significant of these items.

- RF Electronic Systems - the DoD Technology Base activities in radar, at a reduced level (see section 1.4), are in need of reorganization.

- Fuzing - Technology Base efforts appear particularly fragmented.

- Combat Casualty Care Systems - an analysis of techniques other than those used in Vietnam would seem appropriate at this time.

- Material and Devices for Electronic Systems - a more focused effort in III-V compounds seems desirable.

- Gun Technology - a policy decision in mid-caliber gun technology is required, and better Army-Navy coordination in large caliber gun technology would be beneficial.

1.6 Management by Budget Elements and TCPs

The Defense Technology Base is funded from the research, development, test and evaluation (RDT&E) appropriation for the Department of Defense. In terms of DoD budget categories, all 6.1 (research), all 6.2 (exploratory development), and about one-fifth (in monetary value) of the 6.3 (advanced development) budget elements are devoted to the Technology Base. Table I shows a breakdown of this funding. In all, over two hundred individual Military Department and Defense Agency separately appropriated budget elements are involved.

Because of Congressional restrictions on reprogramming between budget elements, management of the Technology Base is heavily influenced by the budget process. More than fifteen principal headquarter-type organizations are involved in the review, prioritization, preparation and defense before the Congress of the Technology Base budget. These

Table I. Approximate Military Department and Defense Agency Technology Base Funding in FY 1976

	DoD Budget Category			
	6.1 Research	6.2 Exploratory Development	6.3A Advanced Development	Total
Military Departments (Army, Navy, Air Force)	300	920	300	1520
Defense Agencies (DNA, DARPA)	40	310	-	350
TOTAL	340	1230	300	1870

headquarter organizations are shown in Table II. Actual program implementation and program direction are closely coupled with these headquarters organizations in some cases (DARPA, DNA, ONR for example), while in other cases, particularly in the military materiel commands which have cognizance over the bulk of Technology Base effort, the effort is implemented in a widespread network of system commands, in-house laboratories, and contract organizations. In all, something like 20,000 individual Technology Base research and development tasks - carried out by small teams of scientists and engineers - are coordinated and funded by the total management/budget system.

From the foregoing brief description, the milieu of management and budget in the Technology Base is complicated, indeed. One might wish it were simpler, but the system does provide a mechanism for prioritizing Technology Base investment relative to the many other operational, procurement, and RDT&E expenditures which the Department of Defense must make, and it does provide significant funding for longer range technological effort essential to the nation's defense. It should be emphasized here that the Task Force has not attempted to evaluate either the efficiency of this structure or what opportunities may exist for improved budget management.

In recent years, alongside the budget-management system described above, there has evolved a separate management assessment system represented by the Technology Coordinating Papers. It has been suggested that the budget elements should in time conform to the TCP organizational arrangements. The Task Force disagrees with this view. The TCPs represent an examination of something in excess of 80% of the Technology Base according to major scientific or technological areas (the specific areas are shown in Table III). There are about a dozen of these documents, and they slice the Technology Base in a manner entirely different from the budget elements. They cut across Services and Defense Agencies, and across organizational elements within the Services. They give a fresh perspective to total DoD investment and technical activity within reasonably coherent scientific and technology areas. While one can easily relate many of the budget elements to specific TCPs, there are also many cases where this is not so. However, the Task Force views the lack of complete and direct correspondence between the TCP structure and the budget structure as a strength, not a weakness. Resource allocation is managed <u>in fact</u> by the budget process, and, although complicated,

Table II. Some of the Principal Organizations Involved in Technology Base Budget and Management

Office of the Director, Defense Research and Engineering (OSD)

Office of the Deputy Director (Research and Advanced Technology) (OSD)

Office of the Assistant Secretary of the Army (R&D)

Office of the Assistant Secretary of the Navy (R&D)

Office of the Assistant Secretary of the Air Force (R&D)

Office of the Deputy Chief of Staff for Research Development and Acquisition, Department of the Army

Office of the Director (RDT&E), Office of the Chief of Naval Operations

Office of the Deputy Chief of Staff (R&D), Air Force

Office of the Deputy Commander for Materiel Acquisition, Army Materiel Development and Readiness Command

Chief of Naval Development, Naval Material Command

Office of the Deputy for Science and Technology, Air Force Systems Command

Defense Nuclear Agency

Defense Advanced Research Projects Agency

Office of Naval Research

Army Medical Research and Development Command

Navy Medical Research and Development Command

Table III. Technology Base Investment by the Military Departments and the Defense Agencies (FY 1976) by Technical Area

Military Department Activities		Approximate $M
1. Electronics		380
2. Weapons		240
3. Aircraft		190
4. Materials/Structures		180
5. Biomedical Science		110
6. Environmental Science		100
7. Land and Sea Military Vehicles		80
8. Physical Science Research		80
9. Human Resources		60
10. Missile Propulsion		50
11. Chemical/Biological Defense		30
12. Environmental Quality		20
13. Other		30
	SUB TOTAL	1540
Defense Agency Activities		
Not included above		330
	TOTAL	$1870M

(A TCP or comparable document has been written for each of the scientific or technical areas described above except for 8, 11, and 13. In area 1, only electron devices are covered in the TCP. In area 4, separate TCPs are written for materials and structures.)

it is a process which seems to meet the needs of the DoD. The TCP, by taking a different kind of slice, is an indispensable form of insurance that the Services and Defense Agency programs are not unnecessarily duplicative and that important areas are not being ignored. The important thing would seem to be only that the budget process can be responsive to changes in direction indicated as needed by the TCP process, not that the two systems correspond in detail.

1.7 Prioritization and the Technology Base

There are two issues: Is the total level of Technology Base funding relative to other defense funding areas reasonable, and is the distribution within the Technology Base reasonable? Task Force observations with respect to the absolute level are:

- At a level of about $1.8B, the Technology Base represents about 2% of the total defense budget. A high technology industrial operation would spend more than 2%, but there is no obvious argument that a 2% level is unreasonable for the Department of Defense.

- The $1.8B expenditure is basically non-duplicatory to other government Technology Base expenditures. The principal Departments and Agencies involved in federally supported technological endeavor are NASA, ERDA, HEW, and NSF. In areas where there might be occasion for duplication (aeronautical and space activities in NASA, nuclear weapon activities in ERDA, medical activities in HEW, etc.), the DoD has a good record of coordination and avoidance of unnecessary duplication.

- There appears to be a sufficient number of good research and development opportunities in defense technology to absorb a $1.8B investment.

If the level is not an unreasonable percentage of the total defense expenditure, if it is not duplicative of other government supported R&D, and if it does not saturate the opportunities for good investment, one can only conclude that the prioritization mechanism that has set the level at $1.8B has operated reasonably well.

Obviously, the level could be a little higher or a little lower without great impact. The Task Force notes that Secretary of Defense guidance in the Five Year Defense Plan calls for an increased emphasis on Technology Base funding in the next few years which should lead to a modest expansion of Technology Base activity. The Task Force is supportive of this guidance. The Technology Base has been greatly reduced in the last 10 years; in the long term, the penalty to the nation for too low a Technology Base investment will be unacceptably high.

With respect to prioritization within the Technology Base, the Task Force observes:

- The prioritization within the Technology Base as a whole is set by the budget-management system described in section 1.6. It is virtually impossible to draw any general conclusions on internal prioritization by trying to compare the 200 plus individual budget elements that make up the total base. However, if one looks at a smaller section of the budget (for example, the 6.1 or the 6.2 budget elements for one of the Military Departments, DARPA's budget, etc.), rationale for prioritization within these sections is apparent.

- The TCP assessment does give a means of making a general assessment of the internal prioritization of the Military Department Technology Base. The distribution of effort by TCP area is shown in Table III. The Task Force, as a matter of collective judgment, felt that the distribution of Table III represented a reasonable fit to mission need and investment opportunity with the possible exception of environmental and behavioral science (discussed in the next paragraph). For example, the military requirements for command, control, target detection and acquisition in modern warfare would certainly dictate a large investment in electronics. That the budget-management system should give this area top priority overall is both reasonable and reassuring. In general, the Task Force was not able to come forth with arguments that would call for an allocation of funding among the different areas grossly different from that produced by the budget-management system.

- The Task Force noted (as have others) that the Technology Base is strongly hardware oriented. The Panel on Environmental and Life Sciences noted that whereas the DoD spends \$1.00 in equipment related technology for each \$19.00 of procurement, it spends only \$1.00 in Life Science related technology for each \$220.00 of military payroll. The Panel further noted that although it is clearly recognized that the capability to carry out a military mission is as much dependent on the man and the operational environment as on the weapon system, the DoD Technology Base invests \$1.00 on hardware related technology to only 9 cents on the environmental sciences and 5 cents on behavioral sciences. This is not to say that equal investment in these three areas would in any way be practical or reasonable, but there is solid evidence that the payoff for improved man performance or improved ability to understand and operate in adverse environments is an increase in the effectiveness of current or older weapon systems without any technological improvements in the hardware at all. A somewhat larger investment in non-hardware technologies, consistent with available investment opportunities, may be in order.

On the matter of prioritization, then, the Task Force concludes that the prioritization of Technology Base effort provided by the budget-management system appears fairly reasonable in an overall way. However, the Task Force notes that since a budget-management system is structured from many detached and rather narrowly-focused parts and since it operates with a bias toward hardware, the situation could be one prone to a degree of misplaced investments, particularly at the detailed level. It is easily conceivable that such a system would place large investments to achieve small improvements in weapon effectiveness without giving any serious attention to the possibility that much smaller investments in improved training methods might reap larger improvements in weapon effectiveness. The situation clearly calls for greater emphasis on the assessment of impact and cost effectiveness of all types of Technology Base investment at the senior levels of Military Department and Defense Agency Technology Base management. Fortunately, the Task Force perceives a trend in this direction, and cites the discussions with the Air Force and DARPA as examples where the necessity for this kind of approach was clearly recognized. Further encouragement of this trend by OSD can be of great service.

1.8 The Impact of the Budget-Management System on Innovation in the Technology Base

The need to weigh Technology Base requirements against other RDT&E requirements, the need to weigh total RDT&E requirements against operational and procurement requirements, and the need to coordinate and review Military Department and Defense Agency programs before submission to OMB and the Congress are the rationale for the budget-management system of the DoD. While the Task Force accepts the rationale, it also notes (as other groups before it) that such an authoritative and layered review structure can be (and has been) inimical to creative and innovative scientific endeavor. Again, fortunately, the Task Force perceives trends in the right direction. The senior management levels in a number of the areas seem more concerned with setting the proper mix of Technology Base investments and with the general scope of the investments than in detailed approval, task by task, of the work to be done. This trend, evidenced, for example, in the Army by block funding for Technology Base work at its in-house laboratories and other delegative acts and by reduction in headquarters staffs, is very encouraging in the view of the Task Force. The flexibility to change direction, to start new initiatives, and to curtail no longer needed activities within a given defined scope of activity is an essential ingredient of top quality scientific endeavor.

The directed trend to larger contract to in-house ratios implies a revitalization of industrial and university-based defense research, also a healthy trend for the nation and contributory to an innovative and creative Technology Base.

Although some of the trends noted above seem to be in what the panel judged to be the right direction, how effective these steps will be remains to be seen. They will surely require continued follow-up from high level management if they are to overcome the inertia to change. Although the present budget management system shows signs of responding to this perceived problem, one can by no means judge that this problem is solved.

2. Technical Basis for Suggested Program Changes

2.1 Opportunities for Funding Increases

This section reviews briefly the reasons for the suggestions listed in section 1.3. The areas discussed represent the panel's judgment of the principal opportunities for increased funding. There were many other possibilities identified by the panels which are discussed in the unpublished, back-up documents entitled "Reports of the Panels."

2.1.1 Training R&D

Training R&D refers to development of improved techniques in personnel training. Such improvements can either reduce training costs or improve operational proficiency or both. Since in FY 1976 the DoD will have 1.7 million persons who will complete at least one training course, even a small reduction in cost can result in a tremendous potential for savings. The panel further notes that better training can often be a cheaper way of achieving increased operational proficiency than trying to improve hardware.

The advance in flight training technology is a good example of an area where considerable improvements have been realized from improved training procedures. The development of part task trainers and full mission simulators for flight training and other training devices has contributed to this success.

The panel believes that the successes in aircrew training using these new approaches can be extended to a number of other training areas. For example, the development of Crew, Group, Team and Unit (CGTU) training shows great promise. There seems to be a considerable number of good ideas now in need of some further R&D to develop them to a useful state. In view of the potential high payoff, the panel recommends this as a good candidate for increased funding.

2.1.2 Software Cost Reduction

Although the DoD spends about $3B per year on software, the lack of mature technology in this area results in frequent failures to meet performance requirements, very frequent schedule slippages, excessive development costs, reduced system reliability, and even more excessive maintenance costs. The problems most often encountered take the form of:

- Inability of management to adequately measure the progress made in software development.

- For large programs, the lack of adequate methods for distributing the work requirements among several programming groups.

- Poorly thought out trade-offs between hardware and software.

- Inability to check the partially completed product against requirements during the development process.

- Inability to control changes during design and development.

- Inadequate provision for improvements and adaptation to new demands.

It is recommended that a major integrated DoD program be established to (1) identify and measure the scope of the problem, (2) identify the major causes of the problem, (3) propose and experimentally evaluate possible solutions to the problem. The goal would be to change software development from the "black art" which it presently is to an engineering discipline based on the relevant parts of computer science. It is important that this program eventually coordinate and absorb the many independent programs within DoD which are attempting to attack these important problems.

The long range goals of the program should be:

- Establishment of a standardized process and technology for software development.

- Establishment of programming standards which improve productivity and yield programs which are more easily adapted to new use and corrected when errors are discovered.

- Development and introduction of improved software development tools, including standardized high order languages.

- o Establishment of improved design documentation techniques.

- o Development of means of predicting the size and complexity of software products.

- o Development of new, more effective quality assurance techniques.

- o Development of more effective procurement practices.

This area is currently identified as a major thrust in information processing and display and funded at $8M in FY 76. In addition, DARPA is exploring certain aspects of the problem area. It is recommended that the program under ODDR&E(R&AT) cognizance be expanded to a level of $11M. However, it is vital that the program be closely integrated and centrally supervised. Experience indicates that if this is not done (a) many overlaps will occur, (b) some projects will be based on extremely localized conditions and irrelevant for DoD as a whole, and (c) some vital areas will go uncovered. For example, there are many parallel and conflicting tool development programs, while research to discover the basic causes of the problems (and hence the nature of the tools needed) is not well funded. The program must be closely supervised by recognized experts in software development, rather than heads of weapons development programs.

In addition, it is recommended that a $2M program be initiated to investigate software avoidance. Software avoidance can take two distinct forms (a) elimination of unnecessary functions, and (b) transfer of some of the responsibilities to hardware. The first alternative is suggested by a talk by the noted Russian computer scientist A. Ershov in which he noted that software developed for the American Navy is much more complex than that on Soviet ships and that the Soviets have experienced fewer software problems as a result. He claims that one can often avoid software by retraining personnel and that this is often by far the most effective way of achieving the desired purposes. The second alternative is suggested by rapid technology advances and the accompanying drop in hardware costs. This suggests that some functions might be more economically performed by hardware. Investigation is needed to ascertain the extent to which both of the approaches are feasible and useful.

One must be careful not to eliminate software problems by transferring the complexity to the other parts of the system. Software problems arise primarily because of our inability to define exactly what is desired and the complexity of the state transitions involved. Both of these problems will be present even if the implementation of the functions is transferred either downward to the hardware, or upward to the personnel. What can be achieved by "software avoidance" will come from the design of more appropriate interfaces between the levels as some of the complexity is simply a result of the wrong choice of interfaces. This last comment is included as a "word of caution"; the problems of software avoidance are clearly worth more investigation than they are now getting.

2.1.3 Gas Turbine Development

In spite of major changes in cycle concept, the improved performance of gas turbine engines has been evolutionary. In the past, a need for a specific new engine always existed. This need acted to stimulate the continuing development effort. At the present time, there is no specific need for a new model gas turbine engine, and, as a result, there is concern that the existing momentum for technical improvement may be lost.

An unfortunate fact in the aeronautical development cycle is that a longer lead time is needed to complete development of a new engine than to complete a new air frame. In the past, this time lag was of little consequence because of a succession of air frame developments. Hence, the engine development community could justify continuing effort. When there is limited air frame development, as exemplified by today's aeronautical programs, it becomes increasingly difficult to justify continuing efforts because of a lack of a need for a specific improved engine. Since aircraft performance is determined by thrust-to-weight ratio and specific fuel consumption, it is vital that the engine development cycle be maintained. It appears that this work has the potential for both increased performance and improved fuel economy. This latter could be particularly important as we face a future with decreasing fuel supplies.

The panel recommends that a vigorous development program in gas turbine engines be continued for at least the next decade with goals of (1) implementing advanced concepts like the "variable cycle" engine; (2) improving the understanding of critical performance items like chrome coated combustors and other engine components and new concepts of seals and bearings; (3) increasing hot part temperatures; and (4) increasing fuel economy.

2.1.4 Environmental Factors Affecting Weapons Systems

A review of a number of weapons systems under development reveals that environmental factors affecting performance are not nearly as well investigated as engineering factors affecting performance. In many systems, atmospheric conditions such as wind, fog, dust, temperature, and precipitation can have extremely important impacts on weapon performance. Often these factors are considered "after the fact," and not as integral parts of the system design process.

A second problem in this area is the lack of detailed knowledge of local weather conditions (e.g., around the FEBA). The lack of this knowledge can greatly reduce the potential effectiveness of many of the currently deployed weapons. In addition to the micro-meteorology of the battlefield, there is also a scarcity of pertinent oceanographic data needed for ASW systems.

The panel believes that R&D should be increased in the three areas related to this problem:

- o Early introduction of the effects of environmental factors into weapons system design;
- o Development of methods for providing localized meteorological conditions to battlefield commanders; and
- o Increased program in oceanography pertinent to ASW problems.

2.1.5 C^3 for Tactical Field Commanders

The importance and problems in command, control and communications at all levels are well recognized in the DoD. The panel feels, however, that C^3 for tactical field commanders is an area which may have received less attention than other phases of this problem. Several problems were identified as needing increased attention relative to the needs of the tactical commander. The panel believes a number of recent technological developments may be helpful in attacking these problems. The developments are in the areas of information processing, sensors capable of measuring a wide variety of desired parameters, and improved communications techniques. We are now capable of paralyzing the commander with too much information. Thus, an important aspect of this problem is to determine the information of importance to the commander and then providing the systems needed to obtain it and present it in readily understandable fashion. This is also an area that could profit from better integration and focus of the present program.

In regard to this problem, the panel particularly suggests work be increased in the following areas:

- Improved responsiveness and flexibility of information systems for tactical commanders.

- Communications systems that function reliably in a battlefield environment including anti-jamming and survivable capability; and

- Improved information display systems.

2.1.6 Digital Controls for Power Plants

A great advantage of a digital control system of any kind is the availability of relevant continuing performance information at a central point. When appropriate, this information can be used for a variety of purposes. For example, a digital control of an engine requires knowledge of the fuel flow rate, the speeds of different parts of the engine, pressures and temperatures and other pertinent information. This information can be used not only to control the engine but also to assess the deterioration of performance and so indicate incipient failure.

The use of analog signals for engine control tended to result in local use of information where it was needed at the moment. Thus, fuel flow may be indicated by fuel pressure, while engine rpm may be indicated by a voltage or a current of pulses. Under the circumstances, the operator, who had many other tasks, monitored these data if they were available for observation to determine if all was well. Digitally, through the use of chip logic elements mounted on the sensors, the data can be put in common form to be used by the central data processor. These data can also be compared, in principle, with data stored in the computer memory to compare the actual performance against the expected performance and thus indicate whether or not the engine is functioning properly. Clearly, this capability has merit since it may make possible emergency modes of operation to preclude catastrophic failures with attendant costs in life and systems. The equipment cost for such a capability must be balanced against lost availability caused by added complexity, and other increased costs.

The panel recommends increases in the following areas:

- o Continued effort must be spent to produce a low cost digital control system, particularly for engines of all types.

- o The level of development of proper sensors should be reviewed and sensors upgraded where necessary. The mating of local logic with the sensors must be developed.

- o Careful experiments must be planned to measure and record engine parameters to learn how to use them for diagnostic purposes and increasing fuel economy.

If successful, the condition monitoring offers the possibility of reducing the number of engine renewals without cause, of increasing the mean time between overhaul, thereby reducing the spare part inventory, preventing catastrophic failures, and improving fuel economy. On balance, a considerable maintenance cost saving is envisioned while operational availability of the weapon system would be increased.

2.1.7 Peacetime Environmental Quality

The current emphasis on environmental quality has led many government agencies to set very conservative levels for the permitted releases of a number of pollutants. Often, very low levels are set because of a lack of any real knowledge of possible effects. Some of these levels could have a very costly impact on the operation of the military establishment. An obvious example is the permitted levels of non-ionizing electromagnetic radiation. In regard to this problem the panel believes the DoD should increase its activities in two areas:

- o Increased R&D in the effects of DoD related pollutants to provide information needed to set reasonable permitted levels.
- o Increased participation with government agencies and panels who have the responsibilities for setting such levels to assure that information from DoD R&D programs is considered and that impact on DoD operations is recognized.

2.1.8 Adaptive Acoustic Arrays

It is becoming apparent that coherence properties of underwater acoustic propagation are better than previously anticipated. Very long arrays can be envisioned which provide means for achieving diffraction limited performance thus greatly increasing sensor system sensitivity and directivity.

In the high energy laser program, a technique for adaptively achieving diffraction limited aperture performance has been developed (Coherent Optical Adaptive Techniques, or COAT). An analogous method using an acoustic reference signal at a distance should provide compensation both for medium inhomogeneities as well as deviations from a straight line in the array. A set of these references set at different angles from the array can be individually commanded "on" as needed when observations in that direction are desired. The aperture is "formed up" using phase shifters, and can then perform in a diffraction limited mode until the medium or array dimensions drive "out of tolerance," or a significant fraction of a wavelength.

Once data is obtained, serious consideration to analog processing using optical or acoustic surface waves should be given. Both are adept at Fourier transforms which are required. Optimum design of arrays and sensors will require knowledge of the "coherence length" of the underwater medium, i.e., the scale over which essentially planar phase fronts can be expected to occur. This information will determine the segmenting philosophy to be employed in the array.

2.1.9 Substitutes for Critical Materials

The panel noted that a number of materials critical to DoD systems are becoming in short supply and already some are available only from foreign sources. In the next few decades it seems likely that this may become a serious problem for the DoD. The panel recommends an increased effort in the following areas.

- Identification of materials where shortages of supply may become a problem.
- Undertake R&D to develop substitute materials.
- Encourage R&D to develop new supplies of material (e.g., the substitution of coal for natural gas as a raw material for plastic).

2.2 Opportunities for Funding Decreases

The section reviews briefly the reasons for the suggestions listed in section 1.4. The areas discussed represent the panels' judgment of the principal opportunities for decreased funding. It should be noted that the panels were instructed to offset any proposed increased by proposed decreases. Thus, although many of these projects may be worthwhile, they come at the bottom of the priority list and represent areas where cutbacks would have the least overall impact on the program. The principal items are discussed here. More detailed information is in the "Reports of the Panels."

2.2.1 Surface Effect Ships

At the advanced development level, it should be possible to state clear, concise and well founded needs for a specific class of vehicles. Although the Surface Effect Ship (SES) represents a new, interesting idea, it seems to the panel that it has properties that would severely restrict its usefulness in many naval operations. It seems clear its lift to draft ratio will be poor. Further, by virtue of its operation near the surface of the water, its velocity is likely to be limited in high sea states. In any reasonable size, it will possess poor ride qualities to the point where they may severely reduce the functionality of the crew. These factors coupled with a lack of a well defined mission and a short range make this project appear to have a very low potential for payoff. The panel believes that further development of this concept is not warranted. It should be noted, however, that the Air Cushion Vehicle (ACV) with potential as a landing craft and the development of SWATH ships both appear promising and are not included in the above comment.

2.2.2 RF Electronic Systems

The work on a variety of RF systems, including radar, communication, IFFN, SIGINT, and ELINT is widespread and diffuse. Although each of these programs has different applications, many contain common elements, antenna, amplifier, signal processors, etc. This appears to lead to considerable overlap. As described in section 2.3.1, the panel believes this area is a good candidate for improvement through better integration and focus. Better integration and focus should produce some cost savings without significant reduction in overall program output.

2.2.3 Special Computers and LSI

Computers and Large Scale Integrated (LSI) circuits have numerous uses in the DoD but they are being developed by a broad based industry for commercial applications. This industrial base is so strong that it appears the reduction of DoD contributions to it would have a minimal impact. The panel believes the DoD can get a better return on its R&D investment in other areas and that the DoD investment should be restricted to a limited number of very unique applications.

2.2.4 Personnel Classification, Selection and Assignment

The classification, selection and assignment of personnel in the DoD is a very important area; however, the R&D on improvement of present procedures seems to be idea limited. Until more ideas are forthcoming, that part of these funds would be better spent in the areas of R&D on improved training procedures which seem to have a number of ideas needing further development (see section 2.1.1).

2.2.5 The Advanced Fighter Technology Integration

In recent years, a number of technological advances have been made in the fields that support aeronautics. These include, but are not limited to, development of high-strength-to-weight-ratio composite materials, direct force-control, fly-by-wire, advanced engine air inlets, independent fuselage orientation, and "high-g" cockpits. These innovations have not been widely accepted, partly because of the feeling that there has been "...a lack of demonstration in an actual flight vehicle."

The panel feels that each innovation also has not been accepted for other reasons. Nevertheless, the unwillingness of the Systems Project Officers to accept high risk, high pay-off innovations, for whatever reasons, seems apparent. Since the panel has supported the importance of acceptance of high risk, high pay-off innovations, it feels it should support this item. However, based upon the material available to it, the panel feels the Air Force proposed AFTI Program is more closely related to development of a new fighter than to technology demonstration. On this basis, the panel cannot see its way clear to support the present AFTI Program. The panel believes that unless an unusual set of circumstances exists, technology demonstration vehicles should be modifications of existing vehicles. In this case, the YF-16 seems like a likely candidate air frame for the extensive modifications needed to demonstrate the several integrated technological elements.

- o It is recommended that the existing AFTI studies be redirected away from a fighter-like configuration and towards an actual technology demonstrator configuration.

(Note: Since this panel met, the Air Force has abandoned the program presented to the panel and adopted a philosophy more consistent with the view of the panel.)

2.3 Opportunities for Integration and Focus

This section reviews briefly the reasons for the suggestions listed in section 1.5. These are areas which, in the panels' judgment, are funded at about the right level but where the panels feel better integration and focus could lead to a more effective program.

2.3.1 RF Electronic System

A principal concern of those of us studying UHF and microwave systems was that the seeming logical division of Technology Base budget management categories (and indirectly performing communities) into functional applications areas, e.g., search radar, target exploitation radar, radar ECM, communications, etc., prevented identification and coordinated prosecution of common Technology Base problems. This division carries the further risk of perpetuating narrow communities of interest, characterized by inflexibility and inertia, which develop products that seldom pass through engineering development and production because of insufficient systems analysis and insufficient consideration of the other systems that must share the spectrum and the platform.

Our views of each of the functional areas is as follows:

- Communications: Funding is relatively low, but only a small portion is spent on the key Technology Base question: How to provide anti-jam/anti-exploitation systems at an affordable cost?

- Search Systems: Funding in Technology Base is very high, although it is hard to separate rf from optical systems. ECCM is a key question.

- Target Exploitation Systems: Funding is moderate, but again it is difficult to separate rf from optical systems. ECCM is probably the key question.

- Radar ECM/ESM Systems: Funding is moderate. ECM and ESM work is not always integrated. We do not know what ESM work is performed under SIGINT program elements. Communications jamming is generally overlooked. Key problems include the recognition and identification and neutralization or exploitation of elusive signals in a crowded spectrum.

If the key operational questions in the functional areas are translated into Technology Base issues as is done in Figure 1, it is immediately apparent that many commonalities exist. Yet our belief is that these commonalities are not being sufficiently exploited and that within a functional area inertia prevents focusing of sufficient resources on the key problems.

Our recommendations, contained in Figure 2, are designed to make it difficult for functional area performers to use Technology Base money to develop systems without having done systems analysis within their functional area and participated in inter-area trade-offs. It is intended that most of the black-box building will be done in 6. 3A and will produce subsystems useful in more than one functional area.

2.3.2 Fuzing

Fuzes are important in many systems including bombs, shells, rockets, etc. The panel found fuze programs to be fragmented and diffuse. All three Services have activities in the area of fuze development. The panel suggests that all these programs be carefully reviewed and that common elements be consolidated. Because of the importance of fuzes, the panel does not suggest any reduction in funds for this area.

FIGURE 1

Tech Base Issues	AJ/Anti-Expl. Comms.	Operational Concerns Radar ECM	Comms. Jamming	Radar ECCM	ESM/ SIGINT
High-Gain Agile Antenna	X	X	X	X	X
Rapid Location & Identification of Signals in a Dense Environment		X	X		X
High Power Broad-Band Transmitter	X	X	X	X	
Programmable Synthesizer/Waveform Generator	(X)	X	X	(X)	
Programmable Spectrum Management	X	X	X	X	X

FIGURE 2

RECOMMENDATIONS

				Present Level (Including E-O)
1.	Reduce	UHF/Microwave Search Systems	$16M	$74M
		UHF/Microwave Target Exploitation Systems	8M	33M
		UHF/Microwave (Radar) ECM/ESM Systems	5M	29M
			$29M	$136M

2. The remaining funds should include $2M per functional area on systems analysis which includes cost/performance/military value studies and trade-offs with other frequencies and techniques.

3. Continue to spend $2M for systems analysis in AJ, Anti-Exploitation Communications.

4. Program $2M for systems analysis in communications jamming.

5. Program $15M for 6.3A development and demonstration of the identified subsystems.

2.3.3 Combat Casualty Care Systems

During the war in Southeast Asia, extremely effective casualty care procedures were developed by the Armed Forces. These techniques saved many lives and resulted in the highest recovery rate of combat wounded ever achieved. However, the techniques developed depended heavily on the total air superiority that our forces were able to maintain and on the availability of nearby hospitals and hospital ships. It is clear that under other battlefield conditions many of the circumstances present in Southeast Asia may not exist. The panel believes it is important to make a careful analysis for other possible conditions particularly those of central Europe and other areas of potential conflict.

2.3.4 Material and Devices for Electronic Systems

Gallium Arsenide, a compound semiconductor of the III-V group, possesses a number of very useful attributes: high electron mobility, large bandgap and therefore high temperature tolerance, high thermal conductivity, and high electro-optic coefficient. These in turn lead to prospects for improved performance in low noise and higher frequency and power microwave diodes and transistors, solar cells, photo-emitters, lasers, light emitting diodes, integrated optics circuitry, signal processing devices, optical modulators, etc.

The realization of the promise, with the exception of light emitting diodes, has been delayed by a variety of material growth and processing problems. In particular, high quality bulk material with well-controlled impurities cannot be obtained commercially on a reliable basis. Moreover, vapor and liquid epitaxial techniques for growing controlled films have proven to be difficult to control. Doping by ion implantation has been elusive, being compounded by the purity and process problems. The lack of effective passivating and insulating layers makes use of the material in an analogous manner to that of silicon extremely difficult.

A systematic, well-organized program in industry where proper people and capital resources exist should be undertaken to break this "logjam" and bring this promising material into regular use. Reliability and failure physics studies should also be undertaken to perfect processes for manufactured devices so they can qualify for MIL SPEC and space use.

With the exception of LEDs, which are more than adequately worked on in industry without DoD funds, there appears little or no reason to work on III-V compounds other than GaAs. Since it takes a great amount of money to get good reliable semiconductor material, whatever money is available in this area ($3M) should be put on GaAs, which is the most important of the III-Vs for military applications.

2.3.5 Gun Technology

Currently, domestic capability in the technology of mid-caliber guns is very limited. A decision must be made whether to develop more domestic capability or to depend upon off shore sources where considerable capability exists at present. It is not clear to the panel which alternative is preferable, but the panel feels that more intensive study of this matter is needed so that a decision can be made soon concerning this problem.

In the area of large caliber guns the panel found several promising developments, including liquid gun propellants and high velocity projectiles. The panel noted that the Army and Navy programs do not seem to be well integrated. The panel believes that the current program could be more productive if there were closer cooperation between the programs of the two Services.