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| Description of document: | Five (5) Defense Science Board (DSB) reports, 1974-1978 |
| Requested date: | 27-June-2017 |
| Released date: | 19-April-2018 |
| Posted date: | 30-July-2018 |
| Reports included: | Report of The Task Force on Electronics Management, 30 April 1974<br>Report of Task Force on Test & Evaluation, April 2, 1974<br>An Analysis of Independent Research and Development/Bid and Proposal, March 1975<br>Task Force on Federal Contract Research Center Utilization, February 1976<br>Evaluation of Strategic Force-Related Technologies, July 1978 |
| Source of document: | FOIA Request<br>OSD/JS FOIA Requester Service Center<br>Office of Freedom of Information<br>1155 Defense Pentagon<br>Washington, DC 20301-1155<br>Fax: (571) 372-0500 |

**DEPARTMENT OF DEFENSE**
**OFFICE OF FREEDOM OF INFORMATION**
**1155 DEFENSE PENTAGON**
**WASHINGTON, DC 20301-1155**

APR 19 2018

Ref: 17-F-1226

This is a final response to your enclosed June 27, 2017, Freedom of Information Act (FOIA) request to this office that asked for six Defense Science Board (DSB) reports (1973 Summer Study Task Force on Electronics; Test and Evaluation; Task Force on an Analysis of Independent Research and Development/Bid and Proposal; Federal Contract Research Center Utilization; DoD Space Shuttle Utilization; and 1978 Summer Study on Strategic Nuclear Balance, Evaluation of Strategic Force-Related Technologies). We received your request on July 5, 2017, and assigned it FOIA case number 17-F-1226.

The Defense Science Board and the Office of the Defense Technical Information Center (DTIC), components of the Office of the Under Secretary of Defense for Acquisition, Technology & Logistics were tasked for search. These searches located five responsive documents, totaling 262 pages which have been loaded to the enclosed CD without excision for your use. Regarding that portion of your request pertaining to the DoD Space Shuttle Utilization report, a no record response is provided since the searches did not locate any responsive document.

If you have any questions regarding this matter, please contact Mr. David Swiney (571) 372-0427 or email at david.k.swiney.civ@mail.mil.

If you are not satisfied with this response, you may contact our OSD FOIA Public Liaison, Jim Hogan, at 571-372-0462 or by email at OSD.FOIALiaison@mail.mil. Also, please note that the Office of Government Information Services (OGIS) offers services to requesters who have disputes with Federal agencies. You may contact OGIS if you have concerns about the processing of your request. Their contact information is provided below:

Office of Government Information Services
National Archives and Records Administration
8601 Adelphi Road-OGIS
College Park, MD 20740
E-mail: ogis@nara.gov
Telephone: 202-741-5770
Fax: 202-741-5769
Toll-free: 1-877-684-6448

You have the right to appeal to the appellate authority, Ms. Joo Chung, Director of Oversight and Compliance, Office of the Secretary of Defense, by writing directly to OCMO Office of the Chief Management Officer, 4800 Mark Center Drive, ATTN: DPCLTD, FOIA Appeals, Mailbox# 24, Alexandria, VA 22350-1700. Your appeal must be postmarked within 90 calendar days of the date of this response. Alternatively, you may use the OSD FOIA request portal at http://pal.whs.mil/palMain.aspx or email your appeal to osd.foia-appeal@mail.mil. If you use email, please include the words "FOIA Appeal" in the subject of the email. Please also reference case number 17-F-1226 in any appeal correspondence.

Sincerely,

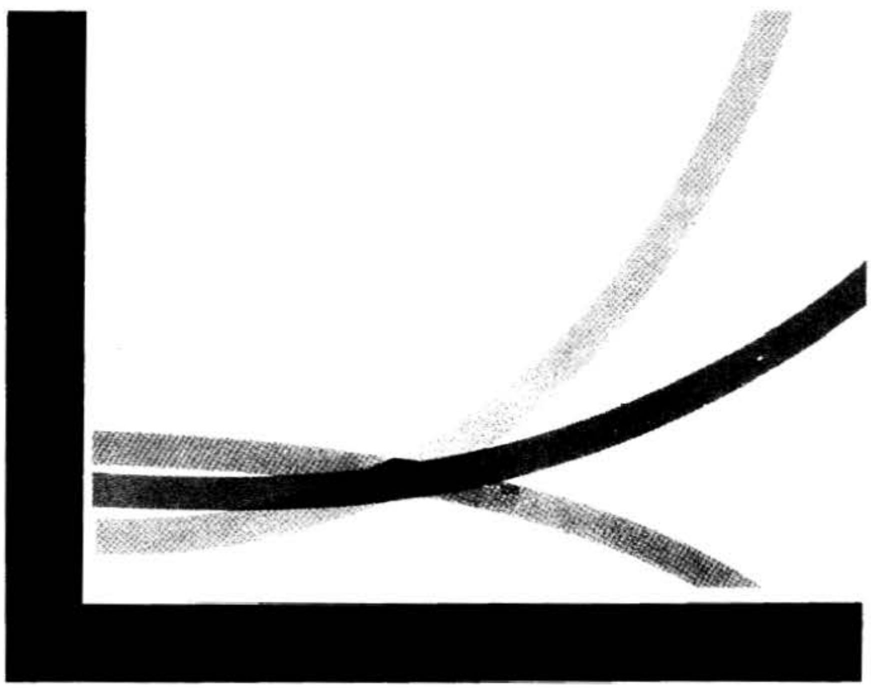
for Stephanie L. Carr
Chief

Enclosures:
As stated

# DEFENSE SCIENCE BOARD

# REPORT OF THE TASK FORCE ON ELECTRONICS MANAGEMENT

**30 April 1974**



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

THE DEPUTY SECRETARY OF DEFENSE
WASHINGTON, D C 20301

AUG 8 1974

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

THROUGH: DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Report of the Defense Science Board Task Force on Electronics Management

I have reviewed this effort and find it of particular interest at a time when we are searching for ways to improve our management methods and reduce costs. I recognize the significance of the Task Force recommendations, and after your verbal report last summer, we started the actions necessary to put some of them into practice. For instance, a special group is now working to find a way to make support costs more visible; an Electronics Panel to the Defense Materiel Specifications and Standards Board has been formed to promote selective electronics standardization; the Defense Advanced Research Projects Agency initiated a study to examine ways to improve maintenance and training aids; and a special group is working on ways to increase the use of warranties on programs. These are just some of the actions already underway, and we are preparing to initiate more, consistent with your recommendations.

The importance of this report is very apparent, and it will receive widespread distribution throughout the Department of Defense. I am personally interested in the progress in implementing the recommendations for improving the management of such a large portion of our Defense budget.

Finally, I would like you to express my appreciation to the Chairman and all the members of the Task Force for their participation in the study. I know these men contributed a great deal of their time and talent, and their recommendations on improving electronics management, when fully implemented, will greatly strengthen our national defense.

W. P. Clements Jr.

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

24 June 1974

TO: THE SECRETARY OF DEFENSE

THROUGH: THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

The attached report of the Defense Science Board Task Force on Electronics Management was prepared at the request of the Director of Defense Research and Engineering. The Task Force, under the Chairmanship of Dr. Richard D. DeLauer, consisted of members with a wide range of experience in industry and Government.

As Dr. DeLauer emphasizes in the Introduction, the Task Force identified high and rising unit cost as well as inadequate field reliability as the main problems facing electronics management. It is on these that the Task Force concentrated. Still, its several recommendations also address more general issues of optimum distribution of resources among initial cost, performance and support. As you know, many of the Task Force's recommendations are already being acted upon by your staff.

The report has been approved by the Defense Science Board and I recommend it to you for your consideration.

Solomon J. Buchsbaum
Chairman
Defense Science Board

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

22 April 1974

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of Task Force on Electronics Management

I am pleased to submit to you the final report of the Electronics Management Task Force. This report summarizes the findings, conclusions, and recommendations of the Task Force during its deliberations in the 1973 Defense Science Board Summer Study at Woods Hole, Massachusetts. It also reflects comments and suggestions provided by Task Force members subsequent to the Summer Study and from others within the Department of Defense and in industry who had an opportunity to review the report during its preparation.

Although our report places a good deal of emphasis on the matter of cost reduction, the Task Force clearly recognizes that there are many other aspects of the military electronics management challenge to be considered in addition to reducing costs. The procurement and ownership of electronics must be managed by the Department of Defense in such a way as to achieve a more equitable distribution among acquisition cost, performance, mission availability, and support costs. The recommendations presented are directed toward this end, and are intended to further the objective of acquiring military electronics systems with optimum operational readiness and adequate performance at minimum cost.

I would like to express my gratitude for the excellent cooperation which the Task Force has received from all quarters during the period of its investigations, and also to recognize the many outstanding contributions which were made to this study by all of the members of the Task Force and its Senior Review Group.

Richard D. DeLauer

Richard D. DeLauer
Chairman, Electronics
Management Task Force

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Lt. Gen. W. W. Vaughn, USA — AMC

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# INTRODUCTION

The Electronics Management Task Force was convened by the Defense Science Board at the request of the Director of Defense Research and Engineering. Among the objectives established for this Task Force were an evaluation, by an independent select group, of the alternative courses of action being recommended by the "Electronics-X" study effort being performed by the Institute for Defense Analyses for DDR&E and ASD/I&L, and the review of the results of related studies and experiments in the area of military electronics cost reduction. The Task Force was requested to develop and recommend a preferred series of specific implementing actions which could have a major impact on development, acquisition, and operating methodology for cost reduction and reliability improvement of electronic subsystems.

The Electronics Management Task Force carried out this assignment as a part of the annual Defense Science Board Summer Study conducted at Woods Hole, Massachusetts from August 6-17, 1973. During this Summer Study period, the Task Force received a number of in-process briefings on the findings and preliminary conclusions of the Electronics-X study, as well as detailed briefings on a number of electronics cost reduction activities currently being carried out under the auspices of the Army, Navy, and Air Force.

For a portion of the study period, the Task Force subdivided itself into six subgroups to hear detailed briefings on specific topical areas, and to hold discussions and to develop specific recommendations in these areas. The subgroup sessions were organized and scheduled in such a manner that each member of the Task Force was able to participate in the deliberations of two different subgroups. These subgroups were:

- *Requirements*
- *Design to a Cost*
- *Standardization*
- *Incentives and Contracting*
- *Field Reliability*
- *Maintenance and Support*

Following the subgroup sessions, the Task Force again convened as a committee of the whole for the purpose of developing the findings, conclusions, and recommendations presented in this report. These findings, conclusions, and recommendations were also presented in preliminary form in a final briefing presented by the Task Force Chairman as a summary report to the Woods Hole Summer Study Group on August 16, 1973.

To prepare for this final briefing, a review session was held on August 15, 1973 at which time the reactions and advice of a Senior Review Group were solicited prior to finalization of the summary briefing. This Senior Review Group consisted of senior commanders from the Army, Navy, and Air Force, representatives of the Assistant Secretaries for R&D of the Army, Navy, and Air Force, and senior representatives from DDR&E, ASD/I&L, and ARPA.

The Electronics Management Task Force is the latest in a series of Defense Science Board Task Forces which have examined various aspects of the problems relating to the cost of acquiring defense systems. Previous studies which have developed a foundation for the present investigation include:

- *Task Force on Research and Development Management (1969)*
- *Summer Study Panel on Weapons System Simplification (1970)*
- *Task Force on Avionics (1971-72)*
- *Task Force on Reducing Costs of Defense Systems Acquisition (1973)*

Each of these studies was concerned with a particular aspect of the problem of defense systems acquisition, and, although each has been able to benefit to some extent from the results of the others, they are intended to be independent and self-contained studies, rather than duplications of previous efforts.

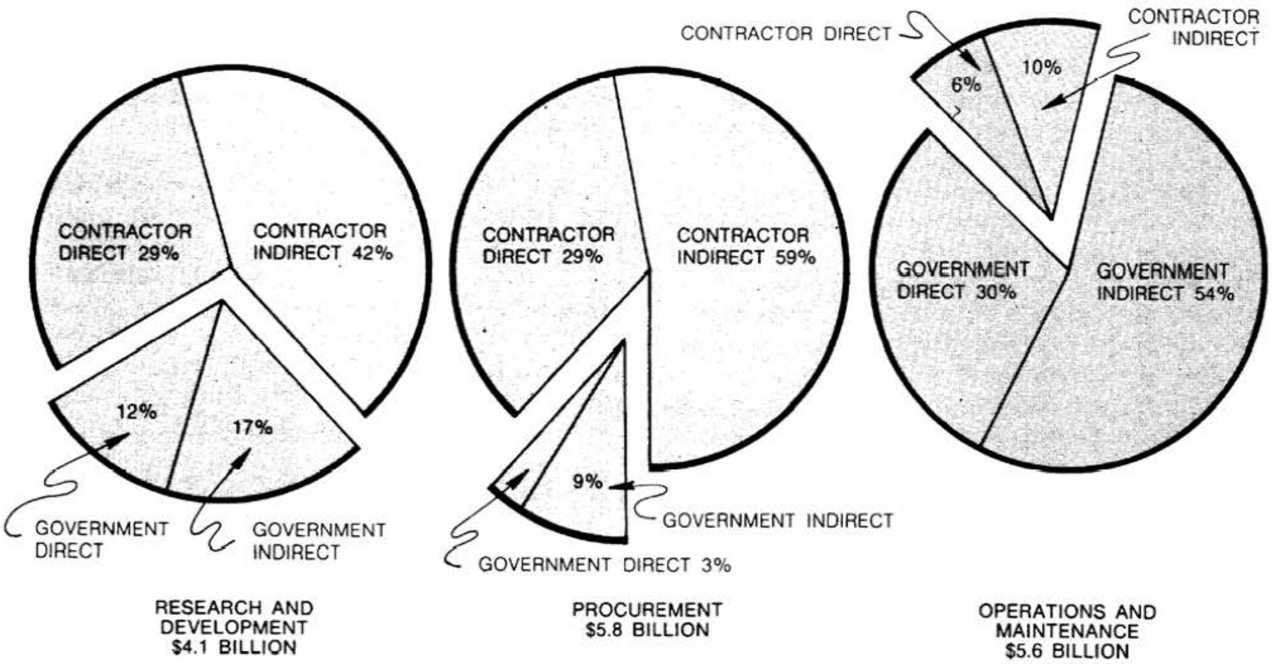
In approaching the question of Electronics Management, the Task Force concluded that the principal current DOD electronics problems are the following:

- *High, and rising, unit costs*
- *Inadequate field reliability*

As a consequence of these two problems, the quantities of electronic equipment available to meet the current military needs are going down.

The FY 1974 DOD budget included an estimated outlay of some $15.5 billion for electronics, in the

**Figure 1–Electronics Budget Cost Distributions**




SOURCE: ELECTRONICS-X STUDY

three budget categories of Research and Development, Procurement, and Operations and Maintenance, as depicted in Figure 1. This was approximately 33 percent of the total DOD FY 1974 budget in these categories. The distribution of the electronics cost allocation among the three budget categories indicates that about two-thirds — nearly 37 percent by industry and about 27 percent by government — of the total electronics budget is allocated for indirect cost.

This Final Report is organized into seven main chapters or sections, each dealing with a different aspect of the military electronics management situation examined by the Task Force. In each section, a specific Finding is presented, followed by a brief Discussion of the major aspects of the problem which were considered by the Task Force. At the end of each section is a Recommendation or series of related Recommendations which, if put into effect by DOD, are believed by the Task Force to have potential for exercising a real impact on the cost and reliability of the electronic systems and equipment which DOD now has in its present inventory and which it will acquire in the years to come. At the end of each section, the anticipated Impact of these recommendations is briefly summarized.

The findings, conclusions, and recommendations of the Task Force on Electronics Management are presented on the following pages of this report, arranged by the following topical areas:

- **I. Full Cost Accounting and Allocation**
- **II. Meeting the Military Needs**
- **III. Uncertainties in Cost and Schedule**
- **IV. Design to a Cost**
- **V. Maintenance and Support**
- **VI. Field Reliability**
- **VII. Standardization**

## SUMMARY OF RECOMMENDATIONS

The primary recommendations of the Electronics Management Task Force are summarized as follows:

1. DIRECT THAT PROPER STEPS BE TAKEN TO EXTEND THE DOD COST ACCOUNTING SYSTEM TO PROVIDE FOR PROPER ALLOCATION OF ALL DIRECT AND INDIRECT COSTS.
2. ESTABLISH PROCEDURES TO INSURE PROPER TOP LEVEL MANAGEMENT REVIEW OF ALL MAJOR ELECTRONIC SUBSYSTEM ACQUISITION PROGRAMS, BOTH THOSE SUBSUMED IN MAJOR WEAPON SYSTEMS AND THOSE INDEPENDENTLY DEVELOPED.
3. DIRECT THAT THE EXPLICIT OPTIONS FOR ALTERNATE WAYS OF MEETING A MILITARY REQUIREMENT BE IDENTIFIED EARLY IN THE CONCEPT FORMULATION PHASE.
4. ASSESS DOD'S IN-HOUSE CAPABILITY IN COST ESTIMATING AND ANALYSIS, THEN UPGRADE THE STATURE OF COSTING IN THE PROCUREMENT PROCESS.
5. TAKE STEPS TO INSURE THAT UNIT PRODUCTION COST IS EXPLICITLY RELATED TO FLEXIBILITY IN PERFORMANCE AND SCHEDULE IN DESIGN TO A COST CONTRACTS.
6. REDUCE THE LEVEL OF IN-HOUSE MAINTENANCE AND SUPPORT BY SOMETHING LIKE 5 PERCENT PER YEAR OR MORE, AND INITIATE ALTERNATE MEANS OF PROVIDING THE NECESSARY SUPPORT SERVICES.
7. ALLOCATE SUFFICIENT RDT&E FUNDS TO UPGRADE THE RELIABILITY OF ELECTRONIC EQUIPMENT IN THE PRESENT OPERATIONAL INVENTORY.
8. CONDUCT A COMPREHENSIVE STUDY OF ELECTRONICS STANDARDIZATION BEFORE ESTABLISHING DOD POLICIES OR FORMAL PROGRAMS FOR STANDARDIZATION.

It should be noted that the concepts discussed in the first section of the report, on Full Cost Accounting and Allocation, are considered by the Task Force to be integrally related to the effective accomplishment of any of the other six topical areas outlined in the subsequent sections. If the basic capabilities for the identification of true costs recommended in Section I are not provided, it will be difficult or impossible for DOD to be able to assess the effectiveness or true impact of any actions which may be implemented as a result of the recommendations in the succeeding sections. It is the consensus of the Task Force that this recommendation on the proper allocation of all direct and indirect costs should have the highest priority of all.

Even if none of the other recommendations herein are adopted by DOD, it is believed that the existing process for acquisition of military electronics would benefit greatly if the initial recommendation is implemented. However, by itself, it will not produce the improvements in the electronics acquisition process which are believed to be necessary and desirable. Without it, the impact of the other recommendations will be extremely difficult to perceive or evaluate, and therefore, funds to implement them will be more difficult to obtain. Thus, there is a strong need to develop accurate measures of the cost of equipment ownership for items in the inventory and to develop techniques for predicting the *total* costs of new systems.

The development of accurate electronics cost and schedule estimates has not been successful to date. While some of the difficulty is due to fundamental uncertainties in future prices and technologies as well as changes in military need, it should be possible to reduce both development and production cost uncertainties in the future. In addition, there is a pressing need to identify costs of ownership for both current and future systems.

In terms of relative priorities for immediate cost-saving impact and improvement in field reliability and mission availability, the Task Force believes that the most significant results can perhaps be realized if the recommendations relating to *Field Reliability* (7) and *Maintenance and Support* (6) are given the next highest priority for implementation after Recommendation (1). Of course, exact prioritization is a very subjective matter, but it appears that the greatest near-term potential lies in taking those actions which will result in improving the reliability and reducing the maintenance and support costs of military electronics presently in, or soon to enter the operational inventory.

Although these two areas possess the greatest potential for immediate payoff, the recommendations given in the other areas are also worthy of the most serious consideration by DOD, as they generally relate to actions which have potential for longer-range impact on the cost, reliability, and availability of military electronics. It should also be noted that, even though considerable emphasis is given to various approaches to achieving electronics cost reductions in the body of this report, the Task Force is firmly of the opinion that cost reduction is only one element of the total electronics management task. The procurement and ownership of military electronics should be managed in such a way as to achieve a more equitable distribution among cost, acquisition, performance, and support. Thus, any follow-on actions resulting from adoption of the recommendations presented in this report should be directed toward all aspects of the principle of providing military electronic systems with optimum operational readiness and adequate performance at minimum cost.

# I. FULL COST ACCOUNTING AND ALLOCATION

*FINDING:* IT WILL BE IMPOSSIBLE FOR DOD TO DETERMINE THE TRUE IMPACT OF ELECTRONICS COST REDUCTION EFFORTS UNTIL BETTER COST ALLOCATION METHODS ARE DEVELOPED.

With respect to military electronics, government "indirect" costs are greater than direct costs (especially in the support phase), and the "indirect" costs are growing proportionately larger with fixed budgets, due both to rising manpower costs and increased equipment sophistication.

At the present time, it is difficult and in many cases not possible to obtain an accurate allocation of the "indirect" costs of electronic equipment owned and operated by the military Services. The government's ability to predict the indirect costs of electronic system ownership is significantly less developed than for the direct costs of ownership (and even these direct costs are frequently difficult to find on a subsystem basis).

Figure 1 indicated that the government indirect costs of electronics O&M in the FY 1974 budget were some 54 percent of the total electronics O&M budget of $5.6 billion, but this allocation, which was derived in the Electronics-X study, is admittedly based on source data of questionable validity. Accurate figures are presently impossible to obtain.

The present government accounting system and procedures used by the DOD do not permit the allocation of costs in such a way that the true impact of electronics acquisition cost reduction efforts, design to a cost contracting, in-house vs. contractor maintenance, contractor maintenance warranty agreements, field reliability improvement programs, and electronics standardization programs can be assessed with any degree of validity. Furthermore, adequate management "corrective actions" cannot be measured.

The DOD has correctly identified the need for determining the life cycle costs of major system acquisitions. While the problem of accurately estimating development and production costs has still not been adequately solved (as discussed further in Section III), it is appropriate to begin to emphasize cost of ownership. However, some words of caution are in order. First, the current deficiencies in cost accounting for O&M and overhead preclude the development of adequate ownership costs for equipment already in the inventory. Second, even when that problem is solved, considerable analytical effort will be necessary in order to use this information to validate and refine estimating techniques for the ownership costs of future equipment. Both steps are necessary; the efforts that are already underway in these areas should be expanded, both in setting up a data system and in gathering and using sample data. But premature contractual requirements for design to a "total" cost should be resisted until more is known.

*RECOMMENDATIONS:*

1. REVISE THE DOD ACCOUNTING SYSTEM TO BETTER IDENTIFY ALL ALLOCABLE DIRECT *AND* INDIRECT COSTS SO AS TO ESTABLISH TRUER COSTS OF ELECTRONICS.
2. IDENTIFY THOSE SUPPORT FUNCTIONS (INDIRECT COSTS) THAT ARE SUSCEPTIBLE TO REDUCTION IF POLICY ALTERNATIVES TO CURRENT SUPPORT PRACTICES ARE ADOPTED.

The following are the anticipated impacts of the above recommendations:

- *Better basis on which to conduct cost benefit analyses to support and measure more effective decision making.*
- *Identification of inadequacies in the ability to identify, compare, and evaluate the allocation of DOD vs. industry overhead support.*
- *Improved ability to assess the real effectiveness of design to a cost, in-house vs. contractor maintenance, warranty arrangements, field reliability improvement programs, and electronics standardization programs.*
- *Reduction of the level (and therefore costs) of "support" required for electronics equipment.*

# II. MEETING THE MILITARY NEEDS

*FINDING:* ABERRATIONS IN THE PRESENT PROCESS OF MILITARY ELECTRONICS REQUIREMENTS DEFINITION AND ACQUISITION CAN AND DO DRIVE THE COSTS OF ACQUIRING SUCH EQUIPMENT. MANY SUCH ABERRATIONS RELATE TO COST-DRIVING ELEMENTS WHICH ARE NOT CONSISTENTLY SUBJECTED TO TOP-LEVEL AND DETAILED MANAGEMENT REVIEW.

Major electronic subsystems which are subsumed in major weapon systems (referred to herein as Class II electronics) and independently developed electronic subsystems intended for use in major weapon systems but not developed as a part of the major system program (referred to as Class III electronics) account for approximately ⅔ of the current DOD electronics acquisition budget (RDT&E plus procurement). The magnitude of each class of electronics in the FY 1974 acquisition budget is indicated in Figure 2. At the present time, Class II and III electronic subsystems are not subject to the Defense Systems Acquisition Review Council (DSARC) type of management review.

Typical aberrations of the requirements/acquisition process which have been found to be present with respect to these Class II and III electronic subsystems include the following:

- *Misunderstanding the Need*
- *Failure to Allow for Uncertainty in the Threat, and in Predicted Cost and Performance*
- *Adding Requirements "Down the Line"*
- *Poor User-Producer Interaction*
- *Insufficient User-Producer Iteration*
- *Pushing for Excessive Performance*
- *Unscheduled Addition of New Technology*
- *Poor Cost and Performance Data Base*
- *Inconsistent Commitment to Size of Buy*
- *"No Requirement"*
- *Contract Constraints and Excessive "ilities" Requirements*
- *Insufficient Comparison Between Product Improvement and New Generation Systems*
- *Insufficient "Reward" for Applying Standardization.*

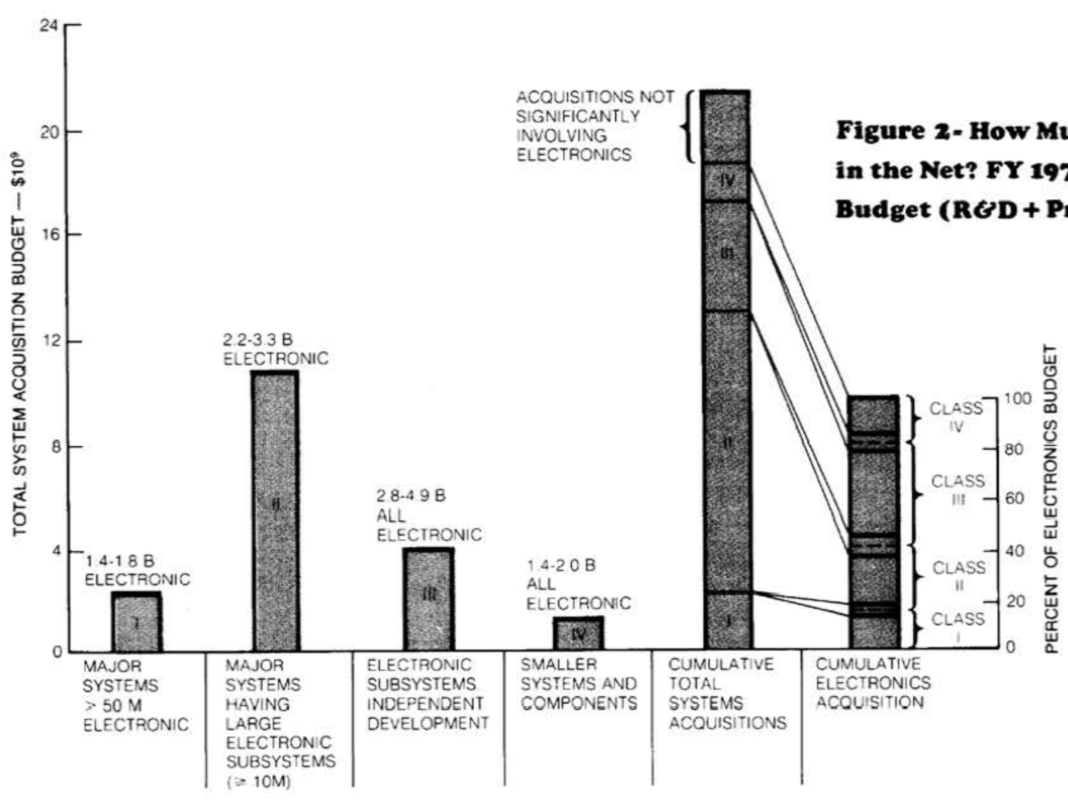



**Figure 2- How Much Gets Caught in the Net? FY 1974 Acquisition Budget (R&D + Procurement)**

The presence of aberrations such as these in a program obviously will tend to drive up the costs of acquisition, and the lack of a formal procedure for management review of the several billions of dollars worth of Class II and III programs, both as to their initiation and their progress, appears to be a significant factor in the growth in cost of their acquisition.

Since these Class II and III programs are not presently subject to formal management review in the same way that major weapon systems programs are, it is possible to expend large amounts of RDT&E money (and even, perhaps, production funds) without a detailed management evaluation having been made of the degree or extent to which such electronic subsystems satisfy or match a stated military threat or an approved military requirement.

The Task Force determined that, in establishing specific electronic system or subsystem requirements, there is a distinct tendency to emphasize the physical characteristics and functional performance required of the equipment, often at the expense of a clear examination and delineation of other critical requirements parameters such as acquisition and life cycle costs, development and production schedules, related process specifications, and quantities required to satisfy operational force needs. This emphasis on performance and configuration can have obviously adverse effects on the cost, schedule, and quantities procurable of the subsystem, and can potentially affect the degree to which the subsystem, even though successfully developed, can be effective in satisfying the stated military need (e.g., too expensive to buy in the required quantities, too late in availability, or very sophisticated and therefore difficult to operate and maintain). Also, a very large penalty must often be paid in terms of total acquisition and/or ownership costs for attempting to obtain electronic equipment which possesses reduced size or weight, or is developed on an overly ambitious schedule, for instance. The penalty associated with attempting to go beyond what is generally accepted as being "reasonable" is typically quite severe. Trying to push the state of the art in one area usually tends to increase the cost and delay the schedule of the entire project, even though the bulk of the effort may be "state of the art."

It was also observed that there is frequently a considerable degree of uncertainty during the acquisition decision-making process as to whether a stated military need could — or should — be best satisfied by developing a new electronic subsystem in sufficient numbers to counter the threat, or by investing in product improvements R&D, then modifying existing weapon systems so as to incorporate the results of the product improvement program.

Data were also examined by the Task Force (generated as a part of the Electronics-X study by the Institute for Defense Analyses and reviewed in preliminary format) which indicated that the average cost growth of a new generation weapon system as compared with the initial system intended to satisfy the military need (in terms of constant dollars) is 4 or 5 times per decade, compared with an average cost growth of about 2 times per decade for product improvement in an existing weapon system. These approximate cost growth relationships are depicted in graphical form in Figure 3, where the general slopes of the curves approximate the cost-ratio of the new and modified systems to the initial system.

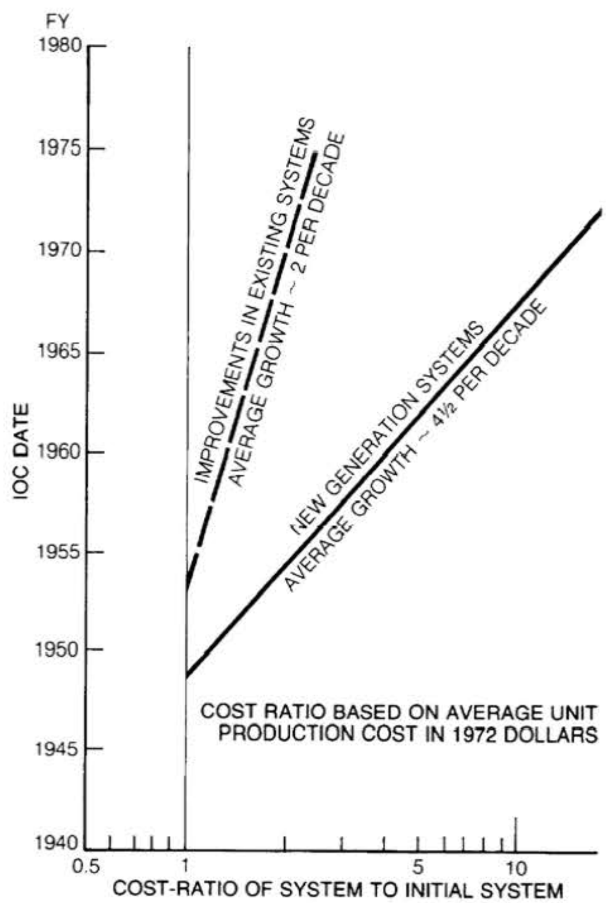


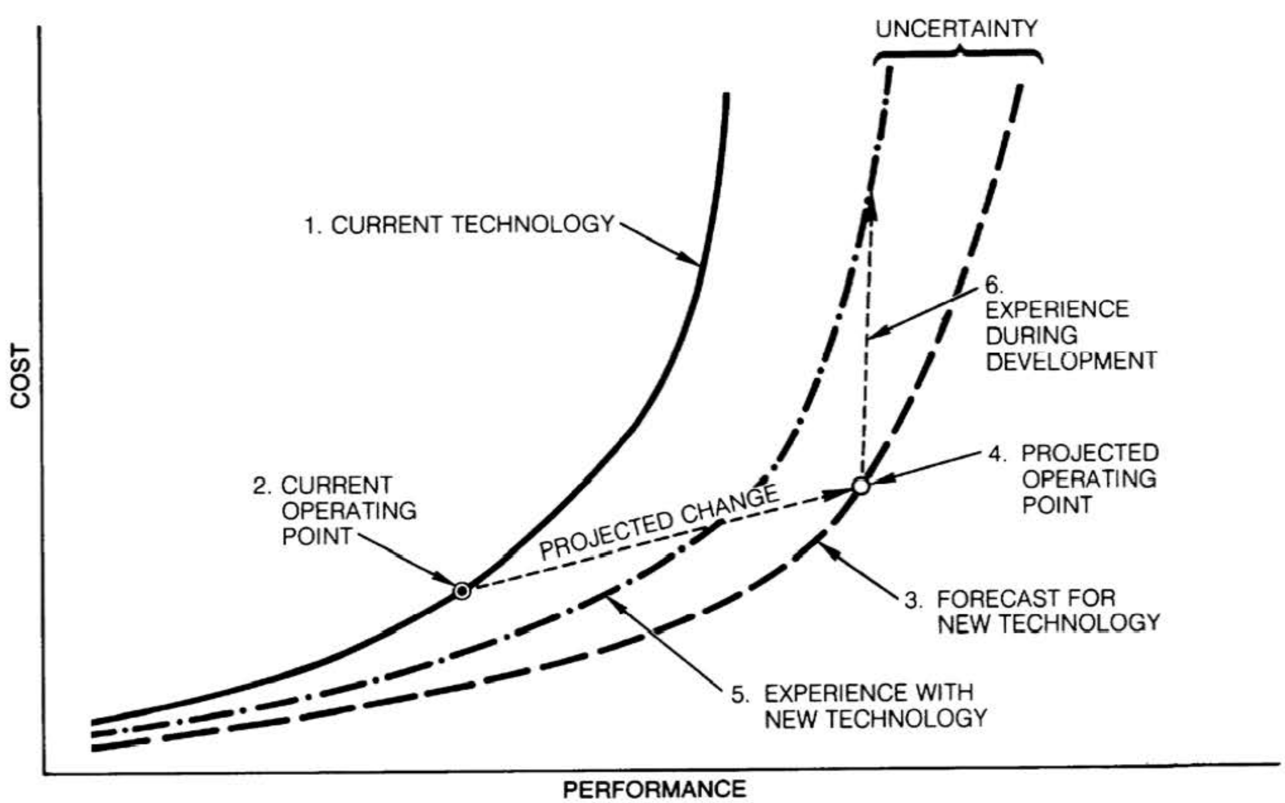

**Figure 3—Progression of Costs**

The lack of clear distinction between new generation and product improvement alternatives can often lead to a mis-timing of new generation acquisition decisions, or to failure to allow for technical and schedule uncertainties which may result from pressing the state of the art too hard, or frequently to cost growth through the proliferation of cost-driving "added requirements" during the design and development phase of the new generation acquisition.

Another factor that is frequently overlooked in making the acquisition decision to meet a stated military need is the impact of technological uncertainty on the acquisition cost and system performance of electronic systems alternatives. As depicted in Figure 4, there is a diverging band of uncertainty associated with a change from current technology to new technology in order to achieve performance improvement. The greater the desired performance increment, the more rapidly the costs tend to increase if the new technology fails to meet its forecast.

As indicated in Figure 4, the cost growth involved in achieving a desired increment of performance improvement can be substantial when the experience with new technology during development is considered. In military electronics practice, it seems to be generally true that advances in new technology are exploited to obtain increased performance rather than to utilize new technology to realize equivalent performance at lower cost and higher reliability. Large jumps in technology are nearly always found to be very costly, and are very seldom undertaken in commercial practice, which prefers to use small advances in technology to achieve improved performance at lower cost (i.e., from the "current operating point" in Figure 4, move down and to the right, rather than up and to the right to the "projected operating point" as shown). Due to the uncertainties in the use of new technology, particularly in the case of complex electronics, the strategy depicted in Figure 4 will nearly always result in higher acquisition costs. This is especially true if performance objectives are held firm when the technology uncertainty is realized.

**Figure 4—Impact of Uncertainty on Systems Acquisition Cost and Schedule**



Most development contracts carry incentives on performance and cost which tend to motivate the contractor against expending additional engineering effort during development to reduce the unit production cost. This type of incentive contracting minimizes current program costs, but not total acquisition cost of electronic equipment.

*RECOMMENDATIONS:*

1. CHANGE THE NEED PHILOSOPHY FROM ONE THAT IS TECHNOLOGY-DRIVEN TO ONE THAT IS DRIVEN BY STATED MILITARY NEEDS: "BECAUSE WE *CAN*, WE *MUST*" IS A PHILOSOPHY WHICH CAN NO LONGER BE AFFORDED.
2. REALISTIC NEED DATES AND QUANTITIES SHOULD BE CONSISTENTLY STATED IN THE DEFINITION OF REQUIREMENTS.
3. MANAGEMENT OF ELECTRONICS PROGRAMS BY THE SERVICES, PARTICULARLY CLASS II AND III, SHOULD INSURE THAT INITIATION AND PROGRESS ARE COMPATIBLE WITH ESTABLISHED GOALS FOR NUMBERS, COST, RELIABILITY, STANDARDIZATION, AND SCHEDULES, EVEN IF PERFORMANCE MUST BE COMPROMISED.
4. ACQUISITION DECISIONS SHOULD CONSIDER NEW GENERATION VERSUS PRODUCT IMPROVEMENT CHOICES; COMPETITION SHOULD BE CONTINUED AS LONG AS FEASIBLE.
5. WHENEVER FEASIBLE, MULTI-CONTRACTOR DESIGN AND PRICE COMPETITIONS SHOULD BE CONTINUED THROUGH DEVELOPMENT AND INTO PRODUCTION.

The impact of the above recommendations should include lower acquisition costs to satisfy military electronics needs, elimination of unnecessary major electronics subsystem development activities, and reduction in the total costs of ownership of electronics subsystems and equipment. With respect to Recommendation No. 5 above, continuing competition for electronics equipment for aircraft and other complex installations may have greater impact if mandatory interface specifications are incorporated into the development specification, thus assuring the interchangeability of competitive equipment.

# III. UNCERTAINTIES IN COST AND SCHEDULE

*FINDING:* **DEVELOPMENT OF ACCURATE ELECTRONICS COST AND SCHEDULE ESTIMATES HAS NOT BEEN SUCCESSFUL TO DATE.**

The accuracy of cost estimates generally varies in direct proportion to the degree of definition of the acquisition program and of the product or end item to be acquired. Unanticipated program and product changes are believed to account for nearly half of the "poor" estimates in weapon systems development and production programs, while the other causes are divided about equally between the effects of inflation and economic forecasting errors on the one hand, and incorrect estimating techniques and methods on the other.

The best cost and schedule estimates for electronics generally come from the lowest organizational element charged with responsibility for performing the effort being estimated. In contracted efforts, the best estimate is typically produced by the functional organizational elements using traditional engineering estimating techniques.

Most electronics cost estimates are made using an engineering pricing approach which requires a detailed preliminary design. This approach is inappropriate for government use in making independent cost estimates, as government agencies normally do not produce detailed preliminary designs, and also lack knowledge of, or access to, appropriate industrial cost factors to be applied to designs to find the estimated costs.[1]

Although there is a strong interrelationship between program costs and program schedules, cost growth can generally not be controlled effectively by means of schedule changes. Cost and schedule estimating efforts must be closely linked in order to emphasize their interrelationships and to provide an increased data base from past experience. Experience has shown that there is nearly always a cost penalty associated with the setting of an unrealistic program schedule. Even when the "realistic" amount of time has gone by, the program generally has cost more than it would have if it had been started originally on the more "realistic" schedule.

Studies of major weapon system development and production programs by the General Accounting Office led to the conclusion that the uncertainty of estimating the costs of the development and production phases during the development phase itself is, on a percentage basis, considerably greater than the estimating uncertainty during the production phase. Some data indicate that the uncertainty in development cost may be as much as 150 percent from DSARC I to DSARC III, while the average production cost growth during the production phase is only about 25 percent. No data were found to exist regarding the growth of the ultimate production unit price as predicted at DSARC I, II, III, and eventually achieved.

Although development cost growth during the development phase appears to be the more acute problem, on a percentage basis, than production cost growth during the production phase, this may not always be the case when absolute cost increments are considered. 150 percent cost growth at the front end of a program (i.e., during the development phase) may be considerably less in actual dollars than is 25 percent production cost growth during the production phase, particularly for programs with any production volume. The total cost of a program involving large production quantities is primarily in the production and support phases.

Therefore, the primary objective should be to manage the development phase to "design to a cost" for the production and support phases. Unfortunately, very little data exist in the DOD sphere to quantify the uncertainty in being able to achieve this objective. However, experience in the commercial electronics field — using both proven technology and advanced technology — suggests that it is indeed possible to achieve unit production cost targets which are quite close to those established by market research and preliminary design at the initiation of the development cycle.

The DOD should now begin to accumulate data on its design to a cost programs in order to quantify the cost uncertainties associated with attempting to predict the subsequent production and support costs of a product during its development phase.

It should also be recognized that uncertainties in estimating the costs of a program (nearly always with an optimistic bias) are in part the inherent result of a desire on the part of the government and the contractor to sell the program to higher management. Cultural pressures

[1] For a more detailed discussion of this point with respect to avionics, see D. J. Dreyfuss, *A Survey of Costing Methods in the Avionics Industry*, The Rand Corporation, WN-8235-ARPA, May 1973.

throughout the entire defense procurement community tend to make estimates progressively below realistically attainable levels. If the true costs of any given program were known at the outset, the program might well never be authorized in the first place. This, of course, would reduce the frequency with which cost growth occurs in defense procurement, but it might also deny the nation vitally needed new military electronics developments.

The parametric approach to cost estimating is generally found to be unsatisfactory in electronics procurement because individual firms are precluded from assembling cost data on design, development, and production experience which may be possessed by their competitors. Thus, each contractor is restricted to his own data and historical pricing experience, which permits only a small and statistically invalid costing data base. The government should sponsor studies of historical costing data on appropriate projects to enable it to fully understand the cost impact of the requirements which are placed on new acquisition programs. It may be possible to develop parametric cost models for electronic equipment types or classes which will permit far more accurate parametric estimating than has been possible up to now. If this is possible, it might eventually result in the ability of the DOD to include *lower cost* concepts instead of *higher performance* concepts, through improved ability to select the option that best meets the funding which is available.

It was also determined that the development of life cycle costs for electronics is at present a very imprecise process. The uncertainties in cost of ownership are very large even at the time of full scale production (DSARC III). This is perhaps due to inconsistency and lack of accuracy in definition of all the relevant ownership cost elements involved, and also due to the inability to quantify the government O&M costs with any degree of confidence, as discussed in Section I above.

*RECOMMENDATIONS:*

1. THE GOVERNMENT SHOULD EXTEND ITS CAPABILITY TO INDEPENDENTLY CONSTRUCT DETAILED COST AND SCHEDULE ESTIMATES FOR ELECTRONICS.
2. THE GOVERNMENT SHOULD DEVELOP ITS CAPABILITIES TO DO PARAMETRIC COST MODELING AND ESTIMATING.
3. THE INPUTS OF GOVERNMENT COST ESTIMATING SPECIALISTS AND PRICE ANALYSTS SHOULD BE CAREFULLY CONSIDERED IN THE DELIBERATIONS OF SOURCE SELECTION TEAMS.
4. THE ELECTRONICS PROCUREMENT CULTURE SHOULD BE CHANGED SO AS TO STRESS AND ENCOURAGE MORE REALISTIC COST AND SCHEDULE ESTIMATING PRACTICES BY BOTH CONTRACTORS AND PROCURING AGENCIES

The following are believed to be some of the more significant impacts which should result from adoption of the above recommendations:

- *More realistic and credible cost and schedule information on which to base budget requests and program management actions.*
- *Achievement of the objectives of electronics acquisition cost reduction, particularly in application of design to a cost concepts.*
- *Creation of an effective check against overoptimism in estimating program costs by the government program office and/or the contractor.*
- *Reduction in the absolute levels of unanticipated cost growth during the acquisition cycle.*
- *Ability to push for more realistic program schedules as a means of limiting or preventing unanticipated cost growth.*
- *Creation of a procurement environment in which reasonable contingency funding provisions (as discussed in Section IV) may be attainable.*
- *Some increase in the cost of government "overhead" functions to carry out the added management activities involved.*

# IV. DESIGN TO A COST

*FINDING:* THE APPLICATION OF DESIGN TO A COST CONCEPTS TO MANY KINDS OF ELECTRONICS ACQUISITION PROGRAMS CAN BE VERY EFFECTIVE IN REDUCING COSTS, BUT IT SHOULD NOT BE CONSIDERED A PANACEA FOR ALL COST PROBLEMS.

In drawing up acquisition contracts to implement design to a cost principles, particular care should be given to the manner in which "what" is to be done, "when" it is to be accomplished, and at "what cost" are specified:

The "design-to" cost should normally be the unit production cost which the government, after detailed analyses by both industry and the DOD, is willing to pay for the desired military capability, and which is compatible with the likely quantities that will be procured, and with current — or otherwise specified — technology.

As indicated in Figure 5, the "design-to" cost should be, ideally, a firm dollar value or point. Given the uncertainties in cost estimation discussed in the preceding section, and the importance of not unduly inhibiting the program manager's flexibility, it may be necessary to establish a narrow range (i.e., a moving "point") for the "design-to" cost, at least in the initial stages of development.

The "design-to" cost objective should normally be applied to the unit production cost, particularly in view of the fact that the deficiencies in the DOD cost accounting system examined in Section I above essentially preclude the life cycle cost target as an attainable option in design to a cost procurements at this time. However, it should be recognized that life cycle costs of electronic equipment are extremely important. If more effective techniques for estimating life cycle costs can be developed, it will be possible to invest in electronic hardware that may be higher in cost per unit, but much lower in cost over its total lifetime. Such tradeoffs of reliability and maintainability for unit production cost should be retained as objectives as the design to a cost concept evolves. Refined "design-to" costs during the development phase should take these factors into account.

- **TO DO "WHAT" AND "WHEN" AT "WHAT COST"?**

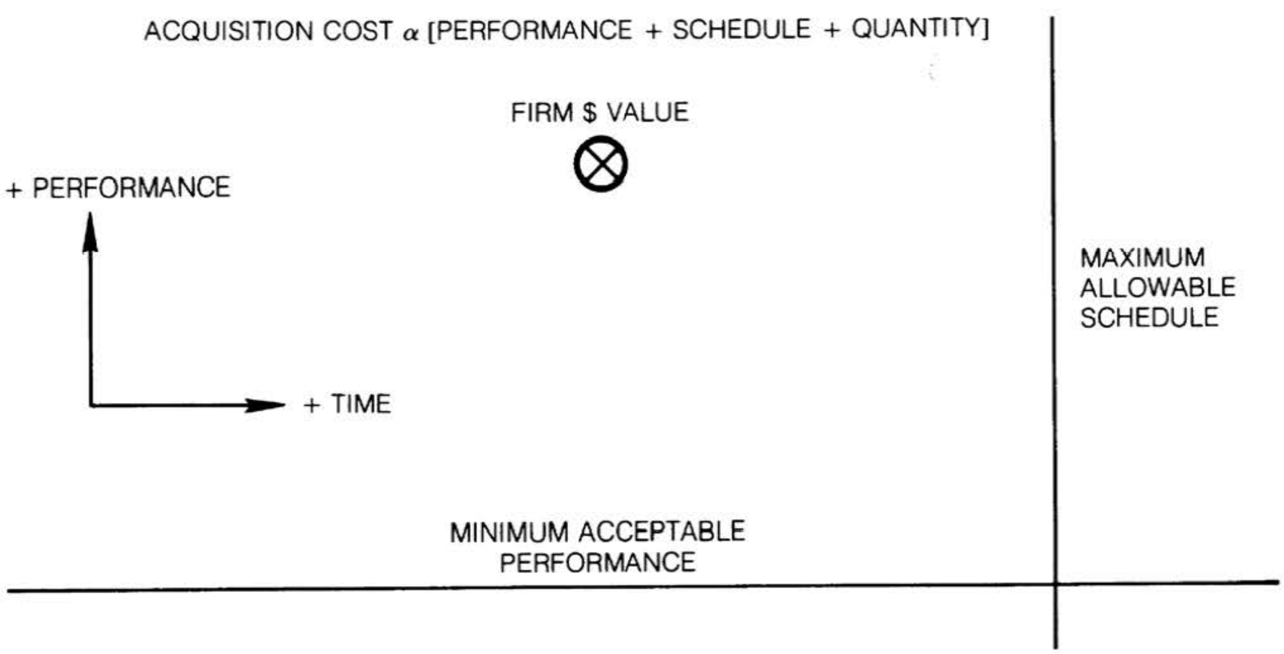



**Figure 5—Design to a Cost**

In order for the contractor to be able to achieve the specified "design-to" cost, the government program manager must have sufficient flexibility in his direction of the project to be able to authorize certain variations in the schedule on which the work will be performed (e.g., specific milestones during the acquisition cycle, or the IOC date for the end product). Such variations should naturally be within certain specified ranges, which may be established in advance by the procuring authority, or perhaps negotiated as the program proceeds. Similarly, the performance requirements for the equipment must be subject to negotiation within certain allowable limits in the same way as the schedule. The significant point to be recognized in design to a cost contracting is that the acquisition cost is in fact a dependent function of performance, schedule, and quantity. If it is desired to maintain an agreed-to "design-to" cost, and the quantity to be acquired is presumably a firm number, then it is clear that the only two parameters which can be varied are performance and schedule.

As depicted in Figure 5, it is necessary to establish the firm "design-to" cost at a point which will allow a certain amount of tradeoff between performance and schedule before either the minimum acceptable performance or the maximum allowable schedule is reached. If the firm dollar value objective is originally set at a point too near either the minimum acceptable performance or the maximum allowable schedule, the program manager will not have sufficient flexibility to trade off these two parameters in such a way as to meet the established "design-to" cost while still maintaining the desired quantity to be procured, the allowable schedule, and acceptable performance for the purpose intended.

Development schedules for electronics are often so short that there is barely sufficient time to select a design which will meet the performance requirement. Once this first-cut design is completed and a good product definition exists for a realistic production and maintenance cost estimate, the contractor can generally recognize opportunities for significant redesign for purposes of reduction of the cost of ownership. However, the schedule constraints of the program usually preclude this second design iteration, (nearly always done in commercial practice), with the result that too many (military) electronic systems go into the inventory with unnecessarily high costs of ownership.

In the evolution of commercial electronic products, it is general practice to first build a model which demonstrates the functioning of the device. The ensuing production design phase is intended primarily to reduce the cost of ownership of the product. This phase generally requires supplementing of the development team with personnel experienced in manufacturing methods, materials and processes, and specific experience in full maintenance. While it would be ideally desirable to include these production characteristics in the initially designed model, commercial experience has demonstrated that production-oriented specialists cannot couple effectively to a project until the basic functions have been defined and a functional working design exists. This is the reason for the two-iteration approach in commercial electronics development. It must be recognized that the second design iteration will increase the cost and duration of the RDT&E phase, but experience demonstrates that it also significantly reduces the unit production cost (or the cost of ownership) of the end product.

In the private sector, planned selling prices normally include substantial margins over manufacturing costs to allow for contingencies. In the DOD case, the budget review process ruthlessly excises contingencies, unless they are cleverly hidden. This is presumably consistent with our federal self-insurance doctrine, but in the real world of budget requests, authorizations, appropriations, and allocations as now practiced in the Congress, OMB, and DOD, it means inevitable and unpopular reprogrammings of dollars and/or quantities. The concept of allowing openly-identified contingency funds in budget submissions at levels as established by OSD guidelines would go a long way toward achieving program stability and avoiding the stigma of "cost growth." Precedent for such an approach exists in our military construction programs where the need for such reserves is much less acute.

In reviewing several of the first applications of the design to a cost concept to military electronics acquisitions (AN/APN 209 Altimeter, AN/ARN 114 Helicopter Loran, Low Cost EW Suite, AN/ARN XXX TACAN, AN/ARC XXX UHF Radio, and MICRON), the Task Force concluded that it will perhaps be several years before the results from these projects become available as guidance for further activity in this area. Since OSD has already directed that design to a cost goals be established for all major

DSARC programs.[1] and since the application of design to a cost contracting principles is rapidly being made to nearly all new military electronics procurements at this time, it seems clear that it will not be feasible to await the outcome of these initial applications before establishing further DOD ground rules and guidelines.

The Task Force observed, however, that it will obviously not be practicable to attempt to implement the design to a cost concept by merely adding a "design to a cost" clause at the end of the typical development contract which already contains contractual terms and conditions which are inconsistent and incompatible with the purpose and objectives of the design to a cost concept. The usual parade of MIL specs and standards, correction of deficiencies clauses, and the like is inconsistent with the management flexibility on which the success of design to a cost contracting depends. If design to a cost is implemented in an inflexible way, it will almost certainly be doomed to failure. Although design to a cost should not be looked upon as a panacea for all of DOD's acquisition problems in any event, it does appear to hold considerable promise for contributing to the solution of some of the problems now becoming very critical in this time of rising costs of acquisition and ownership of military electronics.

*RECOMMENDATIONS:*

1. DON'T ATTEMPT TO INSTITUTIONALIZE THE CONCEPT. USE GUIDELINES RATHER THAN ASPR OR FORMAL DODD. MODIFY ASPR TO ENCOURAGE *FLEXIBILITY* WHERE INDICATED.
2. GIVE PROGRAM MANAGER SUFFICIENT AUTHORITY TO TRADE OFF SCHEDULE AND PERFORMANCE — WITHIN ESTABLISHED LIMITS — AS NECESSARY TO MEET THE "DESIGN-TO" COST.
3. ESTABLISH THE UNIT PRODUCTION COST EARLY IN CONCEPT DEVELOPMENT.
4. DON'T INCORPORATE TERMS AND CONDITIONS IN DESIGN TO A COST CONTRACTS WHICH CONFLICT WITH, OR INHIBIT, THE FLEXIBILITY THE CONCEPT REQUIRES.
5. INCLUDE TIME AND FUNDING FOR A PRODUCTION DESIGN PHASE SO THE "DESIGN-TO" COST GOAL CAN BE ASSURED AFTER BASIC PERFORMANCE IS DEMONSTRATED.
6. DURING SOURCE SELECTION AND PRODUCT DEVELOPMENT, STRESS LIFE CYCLE COSTS (ESPECIALLY RELIABILITY AND MAINTAINABILITY) AS WELL AS UNIT PRODUCTION COST.

Adoption of the above recommendations is believed to provide the DOD with a means of implementing design to a cost which will allow the acquisition of military electronics with significant savings in unit production costs or life cycle costs, or both, without adversely affecting field reliability, mission availability, or quantities necessary to satisfy force requirements. If administered with the proper degree of flexibility, design to a cost can be a very effective tool for controlling the cost growth of military electronics acquisitions in three significant areas:

- *Heightened cost consciousness*
- *Increased cost avoidance*
- *Greater cost reductions.*

[1] W. P. Clements Memorandum "Design to a Cost Objectives on DSARC Programs" June 18, 1973.

# V. MAINTENANCE AND SUPPORT

*FINDING:* SUBSTANTIAL SAVINGS IN THE ANNUAL COST OF MILITARY SUPPORT OF ELECTRONIC EQUIPMENT CAN BE REALIZED IF SIGNIFICANT CHANGES ARE MADE IN THE PRESENT LOGISTIC AND SUPPORT CULTURE.

Of the total FY 1974 Operations and Maintenance budget, the electronics O&M portion is estimated to be more than one-quarter of the total, or greater than $5.6 billion. As discussed in Section I, the actual level is unknown due to limitations in the cost allocation system. The O&M area represents a very promising field for the realization of substantial cost savings, due not only to the absolute magnitude of the annual expenditure, but also because of the particular nature of the activities involved. Many of the procedures and techniques involved in the maintenance and support of electronics are non-military peculiar; that is, they involve activities which are commonly performed in industry, and which can be accomplished under competitive maintenance service contracts with industry insofar as the actual work to be done is concerned.

At the present time, the costs for manpower are estimated to account for perhaps as much as 75 percent of the military electronics maintenance costs. As the transition to an all-volunteer force continues, it can be expected that the costs for manpower — particularly skilled classifications as are needed to perform many electronic maintenance functions — will continue to rise at a very rapid rate. This will further compound the present problems of providing organic maintenance and support for military electronics which have arisen due to limitations of skilled and qualified personnel and rising costs in an environment of heavy pressures on the DOD budget.

There has been traditionally a policy in the government for the use of the private sector for such goods and services as can readily be supplied from that quarter. OMB Circular A-76 has delineated this as federal policy for many years, directing government agencies to obtain goods and services from the private sector except where such procurement would not be in the best interests of the government. In this regard, the Task Force recognizes and supports the need for the military Services to maintain significant capabilities to support much of their equipment, particularly in such circumstances as shipboard service, forward area or hazardous duty locations, non-routine and non-scheduled maintenance of mission-critical equipment, and equipment vital to the maintenance of combat readiness, for example.

But in addition to this type of maintenance and support, there is a large amount of routine depot-level maintenance and support work which could be accomplished as well (or better), and in many cases at lower cost, if assigned to qualified industrial contractors. True comparisons are difficult if not impossible to make under present procedures. Government costing for maintenance and support is done incrementally. Industry is required to consider the total costs associated with the effort, including depreciation, and also must consider return on investment.

In any event, there does appear to be some degree of merit in considering the possibilities of placing more electronics maintenance and support work with industrial contractors on a carefully selective basis — provided that the existing government maintenance and support complex is reduced to a corresponding degree. The Services obviously need to retain an in-house capability to accomplish certain types of maintenance and support, but it is believed that there is considerable room for reduction in the overall level of in-house maintenance and support of electronics without adverse impact on the total military capability.

The Task Force also gave serious consideration to the questions of the applicability and use of various kinds of contractor warranty arrangements for obtaining electronic equipment maintenance and repair for a certain initial period of time after equipment delivery. It appears that the selective use of warranties, particularly in the case of certain types of small, sealed, self-contained, and readily removable electronic units, may offer distinct advantages in contractor reliability design incentives, support cost savings, and increased reliability and availability of such equipment. Here, the practices being followed by the commercial airline industry, with technical support from ARINC, seem to be particularly applicable, or at least worthy of detailed examination by the Services. ARINC cost analyses were examined which indicate that the use of failure-free warranties can be quite cost effective in certain instances, when applied to appropriate types of equipment and when used in selected environments. There are, of course, many unique requirements associated with military logistics which may preclude the use of contractor maintenance warranties in certain applications and with respect to particular types of electronics. But there are believed to be many potential applications (e.g., during the early phases of operational usage prior to design stabilization) where the employment of such warranties would be highly beneficial to the government.

In cases where the use of warranty agreements does appear to be appropriate, care would have to be taken to ensure that current DOD contract boilerplate covering such aspects as Correction of Deficiencies, Value Engineering, and Incentives is examined carefully and modified as necessary to make such terms and conditions consistent with the maintenance warranty features employed.

A reservation was expressed during the Task Force's consideration of warranties as to the value of attempting direct comparisons with such practice in the commercial electronics world, where "business relationships" and informal agreements facilitate warranty administration as opposed to the DOD procurement culture where user-producer relationships are kept at arm's length. Due to such differences, the DOD should be careful not to apply warranties indiscriminately as a solution to all maintenance and support problems. Warranties should be applied selectively and with deliberate speed, but they should not arbitrarily be applied across the board as another "ility" laid on top of other contractual clauses.

***RECOMMENDATIONS:***

1. **DOD SHOULD ACCEPT THE CHALLENGE TO REALIZE MAJOR COST SAVINGS BY MAKING SIGNIFICANT CHANGES IN THE PRESENT ELECTRONICS LOGISTICS AND SUPPORT CULTURE: REDUCE THE LEVEL OF IN-HOUSE ELECTRONICS MAINTENANCE ACTIVITIES BY ESTABLISHING A PROGRAM WHICH HAS EXPLICIT GOALS SUCH AS 5% REDUCTION PER YEAR OVER THE NEXT 10 YEARS.**
2. **ON A CAREFULLY SELECTIVE BASIS, INCREASE THE APPLICATION OF WARRANTY ARRANGEMENTS FOR APPROPRIATE TYPES OF ELECTRONIC EQUIPMENT. WHEN USED, MODIFY OR ELIMINATE INAPPROPRIATE CONTRACTUAL TERMS AND CONDITIONS.**
3. **IMPROVE THE "FEEDBACK" ON FIELD RELIABILITY AND AVAILABILITY TO ASSURE THAT AS THE ABOVE STEPS ARE TAKEN, THE MISSION AVAILABILITY OF MILITARY ELECTRONICS WILL ALSO IMPROVE.**

Among the impacts which may be expected as a result of the above recommendations are reduced overall annual costs for military electronics maintenance and support, a gradual reduction in the total government investment in maintenance facilities, and decreased costs of ownership for individual items in the current military electronics inventory. The flexibility of the military support force should be considerably greater than at present, and the mission availability of military electronics should be at least as good as, if not better than, that presently attainable. It is believed that it should be possible to accomplish a gradual reduction in the level of in-house electronics maintenance without adversely impacting operational readiness if the above recommendations are properly and carefully administered.

# VI. FIELD RELIABILITY

*FINDING:* THERE IS A POTENTIAL FOR SIGNIFICANT COST SAVINGS AND INCREASED MISSION AVAILABILITY IF RELIABILITY OF ELECTRONIC EQUIPMENT IN THE PRESENT INVENTORY CAN BE UPGRADED.

Military electronic equipment in the current inventory poses the following paradox: we have both extremely complex, highly reliable electronic systems in the military inventory, and we also have less complex, but very unreliable systems. Well-designed equipments can be as much as four times more reliable than the median, and poorly-designed equipments can be one-fourth as reliable. In general, the explanation appears to be that acceptable levels of field reliability *can* be achieved if the requisite investment in time and funds for appropriate development testing and production design specifications is made. Where a less comprehensive program is carried out, poor reliability is often the result. In short, we know *how* to achieve high reliability, and we *can* obtain it *if* we are willing to pay for it. Correspondingly, if the military can bring itself to specify electronic equipments that are half as complex, it could not only afford to buy twice as many, but each could operate reliably for up to twice as long.

The mean time between failures (MTBF) observed in operational electronic equipment is frequently far below the value called out in the development specification, and also often well below the value demonstrated during the course of development testing. There are indications that the MTBF called for in the procurement specification is frequently an unreasonably high figure (based on what is considered "desirable" as compared with what the state of the art indicates is a reasonable or achievable value). The specified MTBF frequently bears little or no relationship to what is required by the contemplated military use, also. Considerable design time and developmental test effort is expended in attempting to achieve these unreasonable specification values, most frequently without success. Such overspecification merely dissipates available resources without beneficial return.

MTBF's are frequently demonstrated during developmental testing which are higher than those experienced during field use. This is most often the result of unrealistic test environments which do not sufficiently reflect the operational-use environment or the true operating and maintenance conditions to which the equipment will later be subjected.

Experience has adequately demonstrated that reliability *can* be improved if careful design and testing are continued throughout the development program and *into* the initial production phase. Also, the performance of production testing in a realistic test environment which simulates operational-use conditions is known to enhance operational reliability. But test results can best enhance operational reliability if the *results* themselves become timely feedback to the contractor engaged in further development effort.

Field reliability can be increased if continuing product improvement activities are supported with adequate resources, and if the development contractor is provided with accurate field failure data upon which to base his product improvement efforts and testing.

The availability of proven and qualified electronic parts and components, together with the disciplined adherence to proven manufacturing processes and techniques will enhance the field reliability of military electronic equipment.

The carefully selective use of contractor maintenance warranties should result in improved reliability in certain types of electronic equipment, particularly where the warranty arrangement encourages the routine incorporation of product improvement modifications as a part of the maintenance and repair process.

Software related to electronics hardware also must be tested and evaluated thoroughly. For example, as computerized avionics systems become increasingly complex, software testing and evaluation becomes critical. This will require developers and users to invest time and money in systematic testing of software packages for such hardware as avionics, flight training simulators, and automatic test equipment. An example of the kind of problems that otherwise occur was revealed by a test program on the A-7 system. A major cause of seemingly low reliability of the bomb delivery system that had plagued the Air Force and the Navy for several years of operational use turned out to be software errors in the operational flight program that had not been isolated previously.

Finally, it was observed that the DOD maintenance culture tends to work against the best interests of operational equipment reliability at times due to the fact that maintenance funds must normally be used only to "fix" or "repair" faulty equipment. Operational maintenance money is normally not allowed to be spent to "avoid repairing" equipment, even though this may be less expensive to the government in the long run.

*RECOMMENDATIONS:*

1. DOD SHOULD ALLOCATE SPECIFIC RESOURCES FOR ADDITIONAL RDT&E ON OPERATIONAL ELECTRONIC ITEMS TO IMPROVE RELIABILITY AND AVAILABILITY.
2. FEEDBACK OF FIELD FAILURE DATA TO THE DEVELOPMENT CONTRACTOR SHOULD BE STRENGTHENED, AND FUNDS PROVIDED FOR REDESIGN/RETROFIT WHERE OPERATIONAL PERFORMANCE OR RELIABILITY IS INADEQUATE.
3. TIME AND RESOURCES SHOULD BE MADE AVAILABLE FOR RIGOROUS DEVELOPMENT, SOME LIMITED PRODUCTION, AND OPERATIONAL TEST AND EVALUATION TO CORRECT DEFICIENCIES *BEFORE* EXTENSIVE FIELD DEPLOYMENT IS MADE.
4. DEVELOPMENT CONTRACTORS SHOULD BE ENCOURAGED TO SEEK THAT LEVEL OF LIFE CYCLE COST AT WHICH RELIABILITY AND COST ARE OPTIMIZED.
5. TO THE GREATEST PRACTICABLE EXTENT, DOD SHOULD PROVIDE FLEXIBILITY FOR INTERCHANGE OF DEVELOPMENT, PROCUREMENT, AND LOGISTICS FUNDING TO SUPPORT IMPROVEMENTS IN ELECTRONICS RELIABILITY AND AVAILABILITY.
6. WHEN MTBF OR FAILURE RATES ARE SPECIFIED, THEY SHOULD BE SET AT VALUES WHICH ARE REASONABLE, REALIZABLE, AND CONSISTENT WITH THE EXPECTED COMPLEXITY (OR UNIT PRODUCTION COST) AND THE TYPE OF ELECTRONICS REQUIRED.
7. DOD SHOULD CONDUCT A COMPREHENSIVE STUDY OF SOFTWARE DEVELOPMENT, TEST, AND EVALUATION PRACTICES AS A PRELUDE TO IDENTIFYING AND IMPLEMENTING SPECIFIC FORMAL PROGRAMS FOR ENHANCING SOFTWARE RELIABILITY.

Among the potential impacts of these recommendations for achieving greater field reliability in the operational electronics inventory are the following:

- *Improvement in the present levels of reliability and mission availability of military electronics in the current inventory, which is believed to possess a significant potential for near-term cost savings and increased operational effectiveness.*
- *Increasing the reliability of electronics in the current inventory attacks the cost problem on all three fronts: cost consciousness, cost avoidance, and cost reduction. It will also provide immediate improvement in operational readiness and mission performance capability.*
- *Achievement of the flexibility needed for the interchange of development, procurement, and logistics funding is recognized to be a very difficult task, which may be dependent on management and budget structure realignment.*

# VII. STANDARDIZATION

*FINDING:* **SIGNIFICANT COST SAVINGS AND RELIABILITY IMPROVEMENTS IN MILITARY ELECTRONICS SHOULD BE POSSIBLE THROUGH THE INSTITUTION OF PROPERLY DEFINED AND STRUCTURED PROGRAMS OF ELECTRONICS STANDARDIZATION.**

Electronics standardization poses a dilemma for the Department of Defense: how to realize the advantages of volume buys, less development effort, proven equipment and parts, and reduced maintenance and support costs — while at the same time not raising costs, eliminating competition, stifling technological innovation and evolution, or conflicting with optimum systems engineering.

It must be recognized that there are major differences in the standardization approach which may be applicable to spacecraft electronics, missile electronics, avionics, shipboard and submarine electronics, Army field equipment, and air-conditioned rack electronics to name a few. Each type of electronics has its own particular design requirements and the type of standardization which may be suitable for one type may be wholly inappropriate for others.

Electronic standardization can be applied at any of a number of different levels: subsystems, equipments, modules, boards, parts, LSI standard cells, and semiconductor cells for example. An overall philosophy of electronics standardization does not currently exist within the DOD, but such a philosophy can and should be developed. The specific application of any type or level of standardization to military electronics, however, must always be carefully selected to fit the particular needs of the individual situation.

"Across the board" standardization of military electronics would be in conflict with the DOD philosophy of delegated program management within each of the service departments, and on any given program. The net effect of selective standardization, even if applied with the greatest of care, can be positive only if the overall situation is viewed as a management matrix in which such factors as military need, quantity, performance, reliability, cost, schedule, maintainability, mission availability, state of the art, producibility, and similar considerations are taken into account.

Standardization of electronic parts and components has been applied to military electronics with significant and measurable benefits for many years. With the rapid advent of new technology, standard parts will be at least partially supplanted by such new forms of electronic standardization as standard LSI cells and standard semiconductor processes. The influence of such technological advancements must be carefully considered in the establishment of DOD policy and guidelines for electronics standardization.

Increased emphasis appears to be desirable on tri-service standardization of subsystems and equipments such as aircraft radios, TACANS, and similar types of electronics commonly used by more than one service. This should include increased application of standardized interface / interconnection specifications with form-fit-function specifications (including computer language) of "black boxes" which can be interchangeably employed in various installations.

There are many activities relating to electronics standardization currently underway within various government organizations and agencies, such as the SAMSO and AEC programs for production of critical high-reliability parts and components on captive or controlled production lines in selected industrial contractors' plants, the Navy Standard Hardware Program, and the Defense Materiel Specifications and Standards Board, to name a few.

***RECOMMENDATIONS:***

1. **DOD SHOULD CONDUCT A COMPREHENSIVE ELECTRONICS STANDARDIZATION STUDY — INCLUDING LEVELS, TYPES, TECHNOLOGIES, SPECS, AND IMPLEMENTING DOCUMENTATION — BEFORE ESTABLISHING POLICIES OR FORMAL PROGRAMS.**
2. **ELECTRONICS STANDARDIZATION SHOULD BE APPLIED ONLY ON A CAREFULLY SELECTIVE BASIS WITH DUE CONSIDERATION OF THE PARTICULAR CIRCUMSTANCES.**
3. **THE BEST AREA FOR INITIAL STANDARDIZATION EFFORTS MAY BE IN TRI-SERVICE APPLICATIONS OF STANDARD BLACK BOX INTERFACES.**

If properly formulated and carefully applied, a well-conceived program of military electronics standardization can have a substantial positive impact on acquisition and life cycle costs as well as on the field reliability and mission availability of military electronic equipment and systems.

DEFENSE SCIENCE BOARD

# REPORT OF TASK FORCE ON TEST & EVALUATION

-1

APRIL 2, 1974

*OFFICE OF THE DIRECTOR OF*
*DEFENSE RESEARCH & ENGINEERING WASHINGTON, D. C.*

THE DEPUTY SECRETARY OF DEFENSE
WASHINGTON, D. C. 20301

MAR 3, 1974

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

THROUGH: DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Report of the Defense Science Board Task Force on Test and Evaluation

I have reviewed the subject report and consider it to be a very worthwhile effort. Implementation of its recommendations concerning (1) reliability planning and testing, (2) orderly and systematic software development and testing, (3) the use of functional specifications wherever possible, and (4) early limited production for operational test and evaluation should produce important benefits in our current efforts to reduce both acquisition and total life cycle costs of DoD systems.

The report will receive widespread distribution in the Department of Defense.

I would like you to express my appreciation to the Chairman and to all of the members of the Task Force for their participation in the preparation of this report, which I know required the contribution of large amounts of their time and capabilities. Their willingness to put their talents at the service of the Government to develop their recommendations to improve the system acquisition process is greatly appreciated.

W. P. Clements Jr.

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

18 March 1974

MEMORANDUM FOR SECRETARY OF DEFENSE

THROUGH: DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

The attached report of the Defense Science Board Task Force on Test and Evaluation was prepared at the request of the Director of Defense Research and Engineering. The Task Force was chaired by Dr. Eugene G. Fubini and included members of industry, the Services, and the Office of the Deputy Director (Test and Evaluation), ODDR&E.

The Task Force has summarized and delineated procedures to be observed and general guidelines to be followed for the use of members of the Department of Defense and the developers of weapons systems in preparing, reviewing and monitoring the test and evaluation aspects of development programs. A check list of items that must be covered has been prepared as an additional aid.

The Task Force has endorsed the policies of Department of Defense Directive 5000.3, and developed guidelines to be used in conjunction with these policies. The Task Force noted, for example, that programs which preceded publication of DOD Directive 5000.3 sometimes suffered from organizational breaks with the result that information developed in testing did not reach senior Service management levels early enough to head off significant delays and increased costs. The provisions of DOD Directive 5000.3 regarding test reporting procedures, supported by the Task Force guidelines on this subject, should sharply reduce or eliminate this cause of difficulty.

I wish to call your attention to the recommendations concerning a few broad issues that are of particular significance, because they suggest that changes in our present practices are desirable. The issues and recommendations dealing with them are:

(1) Testing the reliability of systems; the Task Force recommends the development of a reliability growth plan as part of system planning. The plan would include the demonstration of achievement of interim reliability goals, (set at a level lower than the ultimate) prior to commencement of limited production; and a subsequent demonstration of achievement of ultimate reliability goals prior to commencement of full production.

(2) Software development and testing; the Task Force recommends that software, like hardware, be developed under an orderly program plan with monitoring by scheduled milestones.

(3) Early limited production; the Task Force recommends early limited production for operational test and evaluation in the many cases where this is possible without very large early commitment of funds.

(4) Writing of specifications; the Task Force recommends that functional specifications be used in place of design specifications whenever that can be done.

If the recommendations of the Task Force on these four issues are followed, important consequences in the budgeting and scheduling of programs will result.

The report has been approved by the Defense Science Board and I recommend it for your consideration.

Solomon J. Buchsbaum
Chairman, Defense Science Board

DEFENSE SCIENCE BOARD

# REPORT OF THE TASK FORCE ON TEST AND EVALUATION

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, D. C.

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

13 February 1974

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Task Force on Test and Evaluation

On November 14, 1972, Dr. Foster asked me to undertake the responsibility of chairing a DSB Task Force aimed at setting some general rules for T&E activity in DoD. Since that time, the Task Force has been organized and 18 weapon systems examined from the point of view of their T&E activities and their effect on the success of the project itself.

Partially from the examination of these projects, but more especially from the experience of its members, the Task Force drew a number of conclusions and guidelines designed for members of T&E organizations who in the future will be charged with the responsibility of formulating, approving and monitoring T&E programs. The Task Force endorses the policies set forth in DoD Directive 5000.3; most of its efforts were devoted to developing guidelines to be used in conjunction with these policies. These guidelines represent a general consensus of the Task Force members but not every member will agree specifically with every item.

The Task Force found it useful to divide the final report into parts: First, a general section that includes nine short sections written in a form of essays and two appendices - also written in the same form. Second, a list of rules which are applicable to most or all weapon systems. This second part is written in the form of a check list where rules are first given and then followed by examples of applications. The Task Force believes that this report will set useful guidelines to insure that T&E programs are properly prepared and avoid many of the errors made in the past.

In addition to this report, nine additional volumes have been prepared by the Task Force not to be used as a DSB report but to be issued by the T&E organization of OSD. These nine volumes deal with specific categories of weapon systems; they are also prepared in check list form with general rules followed by examples.

Since this is the first report of this kind, it is not complete. I would urge that the DDR&E and Service staffs be invited to collect rules similar to those written in this report so that a second edition of these check lists and essays can be prepared in two years. If this procedure is followed, the quality of the report and its supplements will automatically increase. We hope that this first version forms a useful base on which to build future work.

We enjoyed working with General Starbird and his staff and look forward to receiving comments both from the Board and Members of DDR&E who will review it.

E Fubini

Eugene G. Fubini
Chairman, Task Force on
Test and Evaluation

ACKNOWLEDGMENT

The Chairman wishes to thank the many individuals and their organizations who contributed to this study. This report could not have been prepared without their full cooperation and participation. First, I would like to express my gratitude to the members of the DSB Task Force (see page vii) and their parent organizations, for their invaluable efforts. They contributed a great deal of their own time and talents to this effort and their suggestions and recommendations on how to improve T&E are appreciated.

I would also like to acknowledge the major contributions of the individuals who worked closely with the Task Force members and express thanks to their parent organizations for making it possible for them to serve. They include Mr. Alexander Alexandrovich, Grumman; Dr. Carl Benning, Texas Instruments; Mr. James Bitonti, IBM; Mr. John Buchta, G.E.; Mr. Robert Buzard, LTV; Mr. Victor Friedrich, Office of Assistant Secretary, Army (R&D); Mr. Thomas Glass, Caterpillar Tractor Corp.; Mr. Harold Johnson, Caterpillar Tractor Corp.; Mr. Carrol Killough, Caterpillar Tractor Corp.; Mr. E. W. Neubert, NASA; Mr. Jacob Staab, Caterpillar Tractor Corp.; LCdr. Fred West, CNA.

Mr. Howard Kreiner of ODDR&E and Dr. Joseph Navarro of System Planning Corp. have been not only of tremendous help in the management of this work, but have also contributed many original concepts, precepts and suggestions.

This study could not have been undertaken or conducted without the assistance and cooperation of the many, many others. It would be impossible individually to acknowledge the many people, military and civilian, government and contractor staff, who spent many hours with the DSB Task Force members discussing all aspects of T&E as it relates to the various weapon systems programs. Their information as supplied to the Task Force, is the basic material from which the report has been fashioned.

Finally, I would like to express my warm gratitude for the technical assistance provided by the System Planning Corporation, the administrative assistance provided by ODDR&E(T&E), and the encouragement and support provided by Lt.Gen. Alfred D. Starbird (Ret.), ODDR&E DDT&E.

E. G. Fubini
Chairman

## MEMBERSHIP

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| | |
|---|---|
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| RADM Forrest S. Petersen | ODDR&E, ODD(T&E), Asst. Dir., SSST&E |
| Mr. Howard W. Kreiner | ODDR&E, ODD(T&E), Exec. Secretary of the Task Force |

# LIST OF RELATED REPORTS

Published by Deputy Director (Test and Evaluation)

T&E GUIDELINES FOR MISSILE WEAPON SYSTEMS

T&E GUIDELINES FOR AIRCRAFT SYSTEMS

T&E GUIDELINES FOR SHIP SYSTEMS

T&E GUIDELINES FOR GROUND VEHICLE SYSTEMS

T&E GUIDELINES FOR ASW SYSTEMS

T&E GUIDELINES FOR AIRBORNE ECM SYSTEMS

T&E GUIDELINES FOR AIRBORNE GENERAL SURVEILLANCE RADAR SYSTEMS

T&E GUIDELINES FOR COMMAND AND CONTROL SYSTEMS

T&E GUIDELINES FOR COMMON TEST GEAR

CONTENTS

## I. EXECUTIVE SUMMARY

The Defense Science Board Task Force on Test and Evaluation was established at the request of Dr. Foster, Director of Defense Research and Engineering, on behalf of Lieutenant General Alfred D. Starbird (Ret.), Deputy Director (Test and Evaluation) to develop guidance on test and evaluation through examination of a group of representative weapon systems acquisition programs.

The report assumes a significant amount of knowledge on the part of the reader about existing directives and T&E procedures. The emphasis is on listing those T&E items that past experience has indicated had a profound effect on the success of a program.

This report presents guidance on T&E at two distinct levels. At the most general level, this report (Chapter III) discusses a number of issues which are appropriate for <u>all</u> weapon systems acquisition programs, and are generally matters of basic policy. These issues are:

A. Reliability
B. Computer software
C. Human factors
D. The "T&E Gap"
E. Functional specifications versus design specifications
F. Offense/defense testing
G. Portable instrumentation
H. Ship testing
I. Test Planning

Next, a general checklist of items is presented (Chapter IV) which is organized for a rapid overall review of T&E aspects, generally applicable to <u>all</u> systems development and deployment. The T&E expert in reading this chapter will find many precepts which will strike him as being too obvious to be included in checklists of this type. These items are included because many examples were found where even the obvious has been neglected, not because of incompetence or lack of personal dedication by the people in charge of the program, but because of financial and temporal pressures which forced competent managers to compromise on their principles.

A. SYSTEM RELIABILITY

One of the major factors contributing to degraded weapon systems performance is the lack of system reliability, maintainability, and serviceability, three of the major components of availability. The lack of sufficient reliability has been observed in many of the systems studied by the Task Force.

<u>It should be emphasized that the lack of reliability is not measured only by random failures of components but also by the failures induced by poor hardware design, poor software design, operator errors, wear out, and failure to appreciate the severity of environmental conditions</u>. The above failure modes proved difficult and expensive to overcome when they were allowed to persist into the production article.

Ordinarily, reliability specifications are included in the development contract. For some systems, these requirements tend to be far in excess of what is truly needed or achievable in the program. As a result, reliability specifications set by the developing agency were not met, were progressively relaxed, and, in some instances, were never met. As a consequence, realistic reliability goals were not set, and the program lacked a basis for achievement of realistic goals.

The Task Force therefore concludes that <u>the test and evaluation monitors must require that functional (as contrasted with design) reliability goals be defined, in terms of such operational measures as the probability of completing a mission of specified duration, and that testing adequate to demonstrate achievement of these goals be accomplished successfully</u>.

It is not expected that final operational goals will be achieved during the early stages of the R&D program, but <u>it is necessary that the improvement of reliability be planned during the development and engineering phases, be monitored during these phases, and its achievement proven by testing</u> prior to the major production decision.

Reliability is not a uniquely fixed property of a system, but is achieved progressively in the development of a complex system. Consequently, interim goals, and tests based on these interim goals, must be devised to allow tracking of reliability growth through the program. The alternative of having only a final goal, which is not demonstrable at early stages of the program, allows (if not encourages) contractor and developer alike to overlook the steps necessary before the production decision to achieve the final goal.

Therefore, the progressive attainment of reliability goals must be reviewed at critical points or milestones of the program.

This proposal would, it may be noted, permit the Services to obtain full production approval even prior to the end of the development program, provided reliability growth was tracking well, and thereby reduce the time to operational capability that would have been required if one had to strive for the last most difficult reliability growth.

B. COMPUTER SOFTWARE

Whereas the hardware development was for the most part scheduled, monitored, tested and regularly evaluated, the software development was not.

The Task Force has outlined a software development procedure which should provide for orderly concept program definition, and for continuous testing and monitoring of the software program development, to provide assurance that adequate, efficient, reliable operation will be possible. The increased percentage of development cost introduced by software makes establishment of a suitable procedure a matter of utmost importance.

C. HUMAN FACTORS

User interaction through active participation in the design and execution of test programs is important in all weapon system developments. In systems with a high degree of human interaction--such as Command and Control systems--it is vital that it start with the system design.

D. THE TEST AND EVALUATION GAP

A test and evaluation gap may develop in acquisition programs for expendable equipment between the end of the basic R&D/IOT&E phase and the beginning of the follow-on OT&E, if IOT&E is conducted with R&D prototypes and no provision is made to obtain production articles until after successful IOT&E is complete. This gap, during which no testing occurs, lasted about 2 years on one recent program. The time lost in maturing the production system and the costs to the contractor and the government from the stopping and starting of hardware construction activities as the program moves from R&D to production are highly undesirable.

## E. FUNCTIONAL SPECIFICATIONS VERSUS DESIGN SPECIFICATIONS

Typically, the contractor who is to produce a new system has been given a set of design specifications which the hardware must meet. The contracting service believes that if these design specifications are met, the resulting functional capabilities of the hardware will meet the service needs. Unless the contractor and the government specifically agree otherwise, <u>the government assumes the responsibility of proving that the design specified will perform according to a set of functional specifications (the latter not being binding to the producer)</u>.

If the system does not meet functional specifications, the resulting problem can be so serious that one should conclude that <u>the government should never take the responsibility for the assertion that a specific design meets a specific performance</u>.

## F. OFFENSE/DEFENSE TESTING

To comply most fully with the spirit of the DoD policy, it would be ideal to have test ranges established with the purpose of maintaining in the field and continuously updating systems based on the most modern technology both for defense and offense. For example, it would be necessary to provide inter-netted defense complexes to test a wide variety of offensive weapons. We would require the test ranges to be capable of testing new defense systems against a similar large variety of offensive devices. The costs of these facilities could be overwhelming and may well be not justifiable in some cases.

## G. PORTABLE INSTRUMENTATION

In some cases, in order to have a realistic environment, possibly in simulating a NATO area battle scenario or an amphibious landing, it is necessary to have a portable range instrumentation system available so that the tests can be conducted on and over terrain that provides a realistic operational environment.

## H. SHIP TESTING

DoD Directive 5000.3 states that "to the degree practicable first generation subsystems will have been approved for service use prior to the initiation of integrated operational testing." Subsystem approval for service use, by application of other provisions of the Directive, should be preceded by extensive development and operational test and evaluation. The Task Force urges that "first generation" should be liberally interpreted to include subsystems previously approved for service use but which have been "improved" or modified for the new application.

"When combat system complexity warrants, there is to be constructed a combat system test installation wherein the weapon, sensor, and information processing subsystems are integrated through their interfaces in the manner expected in the ship class." The Task Force believes that all combatant classes and most auxiliary classes of ships equipped for ocean use would be of sufficient complexity to warrant such test installation.

The Task Force would add that where possible, in the case of a large number of ships in a class, no more follow-on ships than necessary for economy and early deployment be contracted before completion of this phase of testing.

## I. TEST PLANNING AND SCHEDULING

The review of past programs indicated widespread inadequate early planning for test and evaluation.

There are a number of actions that should be taken to improve early planning and test conduct. DoD Directive 5000.3 requires that the DCP prepared at the time of the program initiation ". . . will also provide a summary statement of test objectives, schedules, and milestones."

For this summary to be most meaningful, it is necessary that all agencies who will be involved in the tests be consulted to identify testing time, funds, and resources required for the program.

Many checklist items are contained in this report as reminders of those elements that should be considered in developing this overall plan upon which the program is scheduled and costed. Some of these items cover such things as:

- Ensure that the whole system, including the user people, is tested. Realistically test the complete system, including hardware, software, people and all interfaces. Get user involvement from the start and understand user limitations.
- Ascertain that sufficient time and test articles are planned. When the technology is stressed, the higher risks require more test articles and time.
- In general, parts, subsystems and systems should be proven in that order before incorporating them into the next higher assembly for more complete tests. The instrumentation should be planned to permit diagnosis of troubles.
- Major tests should never be repeated without an analysis of failures and corrective action. Allow for delays of this nature.

It is essential that DSARC actions protect the time and the funds provided for T&E from encroachment due to overruns of time and money in other phases of the program.

## II. INTRODUCTION

The Defense Science Board Task Force on Test and Evaluation was established at the request of Dr. Foster, Director of Defense Research and Engineering, on behalf of Lieutenant General Alfred D. Starbird (Ret.), Deputy Director (Test and Evaluation) to develop guidance on test and evaluation through examination of a group of representative weapon systems acquisition programs. (See Appendix A for Terms of Reference.) This report presents the findings of the Task Force through its efforts over a period since 18 December 1972.

The purpose of the report is to offer some guidance to all elements of the Defense Department whose task is to prepare, monitor and execute T&E plans for service use and for presentation to the DSARC.

The report assumes a significant amount of knowledge on the part of the reader about existing directives and T&E procedures. The emphasis is on listing those T&E items that past experience has indicated had a profound effect on the success of a program. Accordingly, it is hoped that these guidelines will be used by the Office of the Secretary of Defense, and the Services, and thus eventually will improve the quality of T&E plans, speed up the approval process of programs and reduce the chances that major difficulties will arise during development programs.

The Task Force found that there was a need for checklists which could be used to assist in the monitoring of the T&E portion of the acquisition program. The guidelines and checklists presented here are the results of lessons hard learned, from examination of weapon systems programs which reflected cost and schedule overruns, inadequate reliability and other defects, as well as those whose histories give examples of methods and procedures for overcoming these problems.

This report presents guidance on T&E at two distinct levels. At the most general level, this report (Chapter II) discusses a number of issues which are appropriate for <u>all</u> weapon systems acquisition programs, and are generally matters of basic policy. The DSB Task Force preferred to present its content in the form of discussions rather than as a set of checklist items. These issues are:

A. Reliability
B. Computer software
C. Human factors
D. The "T&E Gap"
E. Functional specifications versus design specifications
F. Offense/defense testing
G. Portable instrumentation
H. Ship testing
I. Test planning and scheduling

Next, a general checklist of items is presented (Chapter IV) which is organized for a rapid overall review of T&E aspects, generally applicable to <u>all</u> systems development and deployment. The subjects cover the following areas:

A. General planning
B. Scheduling
C. Criteria
D. Resources
E. Costs
F. Issues
   - Performance
   - Operational Realism
     - General
     - Personnel
     - Threat and environment
G. Reporting

The following brief discussion may help clarify the different emphasis of testing on items as the program develops.

Conceptual Phase Before DSARC I

Tests and plans as the service may feel are necessary to support the DCP, or equivalent documentation, related to the concept definition including both operational and technical aspects and their mutual interaction.

Validation Phase Between DSARC I and DSARC Approval for Full-Scale Engineering Development

Tests and plans related to the validation of the concept. Tests must confirm that the operational concept is sound, that all basic technologies have been validated and that materials, components and subassemblies have been tested to such an extent that the related technical risks are minimized. Plans for tests during the full-scale development should be prepared during this phase.

Between DSARC Approval of Full-Scale Engineering Development and DSARC Approval of Substantial Production/Deployment

Testing of materials, components and subassemblies made on items which are in early production engineering stage or ready for it. In addition, tests must identify engineering problems which appear only when the system is "all up" and investigate the character of these problems; the tests will be followed by demonstrations to confirm the readiness of the items for production. In this phase, the operational character of the tests is paramount and an attempt must be made to identify and investigate the operational problems and to assess the eventual operational suitability and effectiveness of the final product.

Production/Deployment Phase After DSARC Approval of Substantial Production/Deployment

Tests with the same purpose as those of the preceding phase but in this case the articles being tested are the final version of production engineering and demonstration tests of operational capability plan an even more important part. Problems of maintenance, reliability and support will be extremely important as are those associated with organizational and employment concepts.

Not all of the systems rigorously follow the above DSARC cycle. One such example is Command and Control systems. To the extent that this type of system goes through the DSARC procedure it is important to remember that the system has to be evolutionary in nature and flexible to accommodate a wide range of users, and because of this, systems (such as C&C) cannot be tested as a typical weapons system; however, it must always be considered and tested as a total system.

In conclusion, the checklists contained in this report should remind the elements of the Defense Department who prepare and execute the plans or who monitor them of a variety of problems which may appear and call their attention to those problems which have been neglected in the past.

NO ATTEMPT IS MADE TO INCLUDE ALL POSSIBLE PROBLEMS; THE GUIDELINES AND CHECKLISTS ARE BASED ON LESSONS LEARNED FROM PAST EXPERIENCES AND PROBLEMS. THEREFORE, IT IS EXPECTED THAT NEW PROBLEMS WILL APPEAR. However, it is hoped that this report will be a useful tool to focus the attention of the reader not only on old problems but also on the new ones.

# III. GENERAL ISSUES

## A. SYSTEM RELIABILITY

One of the major factors contributing to degraded weapon systems performance is the lack of system reliability, maintainability, and serviceability, three of the major components of availability. The lack of sufficient reliability has been observed in many of the systems studied by the Task Force.

It should be emphasized that the lack of reliability is not measured only by random failures of components but also by the failures induced by poor hardware design, poor software design, operator errors, wear out, and failure to appreciate the severity of environmental conditions. The above failure modes proved difficult and expensive to overcome when they were allowed to persist into the production article.

Ordinarily, reliability specifications are included in the development contract. For some systems, these requirements tend to be far in excess of what is truly needed or achievable in the program. As a result, reliability specifications set by the developing agency were not met, were progressively relaxed, and, in some instances, were never met. As a consequence, realistic reliability goals were not set, and the program lacked a basis for achievement of realistic goals.

The Task Force therefore concludes that the test and evaluation monitors must require that functional (as contrasted with design) reliability goals be defined, in terms of such operational measures as the probability of completing a mission of specified duration, and that testing adequate to demonstrate achievement of these goals be accomplished successfully.

It is not expected that final operational goals will be achieved during the early stages of the R&D program, but it is necessary that the improvement of reliability be planned during the development and engineering phases, be monitored during these phases, and its achievement proven by testing prior to the major production decision.

Reliability is not a uniquely fixed property of a system, but is achieved progressively in the development of a complex system. Consequently, interim goals, and tests based on these interim goals, must be devised to allow tracking of reliability growth through the program. The alternative of having only a final goal, which is not demonstrable at early stages of the program, allows (if not encourages) contractor and developer alike to overlook the steps necessary before the production decision to achieve the final goal.

Therefore, the progressive attainment of reliability goals must be reviewed at critical points or milestones of the program. Specifically, these are:

1. At the time the service requests initiation of engineering development, it should be prepared to show a reliability growth plan with sufficient test time and funds to achieve the program goal for reliability achievements.

2. At the time the service requests initiation of limited production, it should be prepared to show:

   (a) By demonstration test results, the system has achieved, at a reasonable confidence level, some percent of the reliability goals for the program, where both confidence level and percent achievement are appropriate to the program.

   (b) There still remains between this time and the end of the development program, sufficient system testing to carry on reliability growth from the point achieved to the program goal for reliability achievement.

3. At the time that the service requests authorization for full-scale production, it should be prepared to show:

   (a) By demonstration test results, the system has achieved, at a reasonable confidence level, nearly all the program reliability goals, if not the final value.

   (b) There still remains between this time and the end of the development program, sufficient system testing to carry on reliability growth from the point achieved, to the program goal for reliability attainment.

   (c) A management plan, test plan and funds to utilize the remaining test time for a vigorous program of reliability growth.

This proposal would, it may be noted, permit the Services to obtain full production approval even prior to the end of the development program. provided reliability growth was tracking well, and thereby reduce the time to operational capability that would have been required if one had to strive for the last most difficult reliability growth.

If the above recommendations are followed, the percentage of R&D funds required will be higher; however, the total program costs should be lower because of the resulting improved reliability and the associated decreased potential for cost overruns.

## B. COMPUTER SOFTWARE

Although most of the programs examined by the Task Force did not use large computer programs, those that did displayed a serious difference in attitude between the development of the computer software and the development of the hardware. Whereas the hardware development was for the most part scheduled, monitored, tested and regularly evaluated, the software development was not. One should not assume that software testing plans are right.

It is more difficult to determine the status of completion of various phases of the software program (as compared to hardware programs), so it is important to explore how the software program is developed and managed as well as how it is being tested. No standard procedure seems to be available within OSD for orderly testing of software items; the Task Force considers this situation unacceptable. Accordingly, the Task Force therefore has outlined a software development procedure which should provide for orderly concept program definition, and for continuous testing and monitoring of the software program development, to provide assurance that adequate, efficient, reliable operation will be possible.

The increased percentage of development cost introduced by software makes the establishment of a suitable procedure a matter of utmost importance. For this reason the procedure suggested is given in this report in some detail, in Annex A. The reader is urged by the Task Force not to assume that the editorial decision of including the procedure in an annex rather than in the text, indicates a low priority for this recommendation.

## C. HUMAN FACTORS

The Task Force turned up a surprisingly large number of instances in which designs lacked adequate human factor considerations, and, notable from a T&E point of view, many in which development engineering testing did not lead to early awareness of the problem. The problems were varied: excessive sound levels, insufficient space, or inconvenient access, even poor placement of controls and readouts sufficient to double the manpower requirements for operation of a system.

The solution is obvious: first, more attention should be given to human factors in the initial design, during modifications and updating of equipment; and second, T&E should be planned and conducted so as to ensure that human factor requirements have been adequately considered during design, demonstrated at the first mockup of the system, and monitored throughout subsequent testing.

<u>User interaction through active participation in the design and execution of test programs is important in all weapon system developments. In systems with a high degree of human interaction--such as Command and Control systems--it is vital that it start with the system design.</u>

## D. THE TEST AND EVALUATION GAP

A test and evaluation gap may develop in acquisition programs for <u>expendable</u> equipment between the end of the basic R&D/IOT&E phase and the beginning of the follow-on OT&E, if IOT&E is conducted with R&D prototypes and no provision is made to obtain production articles until after successful IOT&E is complete. This gap, during which no testing occurs, lasted about 2 years on one recent program. The time lost in maturing the production system and the costs to the contractor and the government from the stopping and starting of hardware construction activities as the program moves from R&D to production are highly undesirable.

There are three basic alternatives for addressing the acquisition of expendable equipment for the later OT&E phases:

1. Plan at the start of engineering development for additional <u>R&D hardware</u>, to be R&D funded and built for IOT&E and for <u>an additional phase of testing to cover the T&E gap</u>.

Paragraph 5 of DoD Directive 5000.3 recognizes that additional phases of OT&E may be needed prior to the availability of production hardware. In this case, every effort would be made to production tool each subsystem as soon as it could be qualified. In this way, the R&D would gradually evolve into the production configuration.

2. Plan the development and OT&E phases so that DT&E and IOT&E hardware is funded with R&D. Early in the DT&E effort, defend long lead time production funding and seek production funds for low rate pilot production. Again, emphasize early conversion to production configuration so that the evolving production configuration hardware will be available to continue the OT&E immediately after the IOT&E. The testing would be continuous and at a point where all the qualified subsystems were in production, the follow-on OT&E would be initiated.

3. Simply allow the gap to exist, which may be preferred when the effort to reduce the gap would require the commitment to a very large percentage (or amount) of the expected program cost before T&E assurance of a successful product could be obtained.

For further discussion on the T&E gap solutions, the reader is referred to Annex B.

## E. FUNCTIONAL SPECIFICATIONS VERSUS DESIGN SPECIFICATIONS

Typically, the contractor who is to produce a new system has been given a set of design specifications which the hardware must meet. The contracting service believes that if these design specifications are met, the resulting functional capabilities of the hardware will meet the service needs. Unless the contractor and the government specifically agree otherwise, the government assumes the responsibility of proving that the design specified will perform according to a set of functional specifications (the latter not being binding to the producer).

If the system does not meet functional specifications, the resulting problem can be so serious that one should conclude that the government should never take the responsibility to tie a design to a performance. An alternative solution is to assign contracts of a system or device on the basis of "form, fit, function and interfaces." Then the interchangeability and performance are clearly the responsibility of the producer. This leads to the following:

number of national test ranges available, it is not clear that they could adequately accommodate all new system OT&E programs. In some cases, in order to have a realistic environment, possibly in simulating a NATO area battle scenario or an amphibious landing, it is necessary to have a portable range instrumentation system available so that the tests can be conducted on and over terrain that provides a realistic operational environment.

For these reasons the DSB Task Force recommends serious consideration of such instrumentation. Further, because of the "free play" type testing usually conducted during OT&E, the portable instrumentation must be capable of covering large areas and providing data on player location and events. Such portable instrumentation is especially pertinent to missile and aircraft testing.

## H. SHIP TESTING

The testing of ships considered as a system rather than an aggregate of items is a new concept. There could be a tendency not to give serious consideration to Directive 5000.3 because of the many loopholes left in the directive. The Task Force believes that it must restate, at greater length, the procedures given in Directive 5000.3 for testing ships, and emphasize the importance of not bypassing any of the steps.

DoD Directive 5000.3 states that "to the degree practicable first generation subsystems will have been approved for service use prior to the initiation of integrated operational testing." Subsystem approval for service use, by application of other provisions of the Directive, should be preceded by extensive development and operational test and evaluation. The Task Force urges that "first generation" should be liberally interpreted to include subsystems previously approved for service use but which have been "improved" or modified for the new application. It is essential that the DCP for the ship program identify, and make provision for resolution of any remaining uncertainties about the qualification of critical subsystems for inclusion in the ship. Note that the provision of the Directive relates to initiation of integrated testing, rather than to initiation of construction of the lead ship. It is assumed that the lead ship could be well into construction before all equipments were service approved.

GUIDELINE:

When the designer and producer are different, tests should be conducted to ensure that the producer meets the design specifications. The test plan should make provisions for the case when the design specifications are met but the performance is below requirements. In this case it may be necessary to do additional R&D work. Normally, the producer will be assigned this task.

## F. OFFENSE/DEFENSE TESTING

The Department of Defense Directive 5000.3 states, "OT&E is that test and evaluation conducted to estimate the prospective system's military utility, operational effectiveness, and operational suitability.... OT&E will be continued as necessary during and after the production period to refine these estimates, to evaluate changes, and to reevaluate the system to ensure that it continues to meet operational needs and retains its effectiveness in a new environment or against a new threat."

Some new systems go through the OT&E without being exposed to any offense/defense environment.

To comply most fully with the spirit of the DoD policy, it would be ideal to have test ranges established with the purpose of maintaining in the field and continuously updating systems based on the most modern technology both for defense and offense. For example, it would be necessary to provide inter-netted defense complexes to test a wide variety of offensive weapons. We would require the test ranges to be capable of testing new defensive systems against a similar large variety of offensive devices.

The costs of these facilities could be overwhelming and may well be not justifiable in some cases. Criterion C-5 in our general checklist refers to this issue and gives the basis for analyses of this tradeoff. An example where this type of activity was in fact conducted and the cost justified was in the test range designed to validate our ABM concepts.

## G. PORTABLE INSTRUMENTATION

DoD Directives 5000.1 and 5000.3 stress that OT&E will be conducted in as realistic an operational environment as possible. Although there are a

"When combat system complexity warrants, there is to be constructed a combat system test installation wherein the weapon, sensor, and information processing subsystems are integrated through their interfaces in the manner expected in the ship class." The Task Force believes that all combatant classes and most auxiliary classes of ships equipped for ocean use would be of sufficient complexity to warrant such test installation.

The foregoing words allow either a land-based or at-sea installation, and, possibly, a good deal of latitude about the detail to be incorporated in the installation. It is recommended that the installation, at a minimum, include accurate, geometrically identical spacing and placement of all critical equipments, at least mockups of other installed equipment in spaces, cable and utility conduits and piping identical to that to be installed in the production ship, antennas, lighting and ventilation as in the production ships (even if augmented for non-test repair and modification), and provision for feeding the test system either real or simulated input as it would occur in operational situations. Real inputs should be used if at all possible and simulated inputs permitted only in cases such as sonar on a land-based test installation.

If the new class of ships incorporates advancements in propulsion technology, there should be a propulsion test site. The Task Force feels that its interpretation of the policy of 5000.3 as it applies to a combat systems test site is equally applicable to a propulsion test site if one is required.

The Directive also states, "for all new ship classes continuing phases of OT&E on the lead ship will be conducted at sea as early in the acquisition process as possible for specified systems or equipments and, if required, full ship operational evaluation to the degree feasible." The Task Force would add that where possible, in the case of a large number of ships in a class, no more follow ships than necessary for economy and early deployment be contracted before completion of this phase of testing. The Task Force also urges that contract methods be devised to minimize the cost impact of changes found necessary in such operational testing.

The Task Force concurs that there should be prototyping of the entire ship and combat system if the new ship's hull design will contain technological advancements and/or significant scale-ups of previously proven technologies, with operational tests at sea prior to production commitments to follow ships.

## I. TEST PLANNING AND SCHEDULING

The review of past programs indicated widespread inadequate early planning for test and evaluation.

The original program estimates were based on incomplete considerations of time and cost implications of the test program. Once the test program requirements were established, there was a great reluctance to modify the schedule or cost estimates. In most cases, the result was inefficient testing and evaluation and cost and schedule overruns.

There are a number of actions that should be taken to improve early planning and test conduct. DoD Directive 5000.3 requires that the DCP prepared át the time of the program initiation ". . . will also provide a summary statement of test objectives, schedules, and milestones."

For this summary to be most meaningful, it is necessary that all agencies who will be involved in the tests be consulted to identify testing time, funds, and resources required for the program.

Many checklist items are contained in later chapters of this report as reminders of those elements that should be considered in developing this overall plan upon which the program is scheduled and costed. Some of these items cover such things as:

- Ensure that the whole system, including the user people, is tested. Realistically test the complete system, including hardware, software, people and all interfaces. Get user involvement from the start and understand user limitations.
- Ascertain that sufficient time and test articles are planned. When the technology is stressed, the higher risks require more test articles and time.
- In general, parts, subsystems and systems should be proven in that order before incorporating them into the next higher assembly for more complete tests. The instrumentation should be planned to permit diagnosis of troubles.
- Major tests should never be repeated without an analysis of failures and corrective action. Allow for delays of this nature.

It is essential that DSARC actions protect the time and the funds provided for T&E from encroachment due to overruns of time and money in other phases of the program.

The DSARC procedures and attitudes can be used in a positive fashion to improve the test planning and scheduling performance by being aware of the situation as discussed above and mainly by insisting upon adequate contingency planning in preparation of the initial DCP, by encouraging thorough updating of the test planning in the Validation Phase before the initiation of full-scale development, and by carefully avoiding the establishment of any deadline or reviews that foster a feeling that testing must be completed by a given date.

## IV. GENERAL CHECKLIST ITEMS

The set of checklist items presented in this chapter is oriented toward good procedures and practices relative to T&E. This checklist contains items which for the most part cut broadly across both weapon system types and time phasing of testing. It should serve as a basis for a rapid, if not exhaustive, overall review of a test plan. The organization has been chosen to facilitate just such a quick review, with the expectation that this will be followed by a more thorough examination against the specific checklists. Several of the items in the General Checklist have applicability under several headings (e.g., Scheduling and Resources) and are repeated under each, perhaps with different emphasis. The subjects touched on by the checklist are:

A. General Planning
B. Scheduling
C. Criteria
D. Resources
E. Costs
F. Issues
    - Performance
    - Operational Realism
        - General
        - Personnel
        - Threat and Environment
G. Reporting

## NOTE

The T&E expert in reading this chapter will find many precepts which will strike him as being too obvious to be included in checklists of this type. These items are included because many examples were found where even the obvious has been neglected, not because of incompetence or lack of personal dedication by the people in charge of the program, but because of financial and temporal pressures which forced competent managers to compromise on their principles. It is hoped that the inclusion of the obvious will prevent repetition of the serious errors which have been made in the past when such political, economic and temporal pressures have forced project managers to depart from the rules of sound engineering practices.

It is the conviction of the Task Force that, in the long run, taking short cuts during T&E to save time and money will result in significant increases in the overall costs of the programs and in the delay of the delivery of the corresponding weapon systems to the combatant forces.

## A. GENERAL PLANNING

The following are checklist items contained in this section:

1. Effects of Test Requirements on System Acquisition Strategy
2. Test Plan Coverage
3. Test Requirements and Restrictions
4. Trouble Indicators
5. Effect of Incentives on Test and Evaluation
6. Software Testing
7. Requirement for Test Rehearsals

1. EFFECTS OF TEST REQUIREMENTS ON SYSTEM ACQUISITION STRATEGY

<u>The acquisition strategy for the system should:</u>

(a) Allow for a sufficient time between the planned end of demonstration testing and major procurement as contracted with limited production decisions so that there is a flexibility for modification of plans which will be required during the test phases of the program;

(b) Ensure that sufficient dollars are available not only to conduct the planned T&E but to allow for the additional T&E which is always required due to failures, design changes, etc.;

(c) Be evaluated relative to constraints imposed by:

- The level of system testing at various stages of the RDT&E cycle,
- The number of test items available and the schedule interface with other systems needed in the tests, such as aircraft, electronics, etc.,
- Support required to assist in the preparation, conduct of the tests, and the analysis of test results;

(d) Be evaluated to minimize the so-called T&E gap caused by a lack of hardware. Specifically, a test gap can result if funds are not applied until the results of IOT&E are known because of the required lead time for production planning, production facilities, and tool and production hardware. (See the T&E gap discussion in Volume 1, Chapter II.)

2. TEST PLAN COVERAGE

<u>Every test plan should include clear statements of:</u>

- The overall purpose of the test
- Critical issues with respect to operational requirements
- The major test objectives
- The schedule of test milestones
- The major resources required
  - Test environment, facilities, and instrumentation
  - Operational environment
- The organizations which will conduct the test program
- The analysis and evaluation approach

## 3. TEST REQUIREMENTS AND RESTRICTIONS

Tests should:

- Have specific objectives
- List in advance actions to be taken as a consequence of the test results
- Be instrumented to permit diagnosis of the causes of lack of performance including:
  - "Random" failures
  - Design induced failures
  - Wear out failures
  - Operator error failures
  - And those as a result of accidental environmental conditions.
- Not be repeated if failures occur, without a detailed analysis of the failure. Most likely, the failure will not go away. Note that this rule, essential as it is, can be violated if the failure mode analysis reveals that, even if the same failure reoccurs, very useful results can still be obtained about the performance of other subsystems or components.

## 4. TROUBLE INDICATORS

Establish an early detection scheme for top government and contractor management to determine that a program may be becoming ill.

At this time there may be a good possibility of recovery. Some of the indications of trouble are:

- A test failure
- Any repetitive failure
- A revision of schedule or incremental funding that exceeds the original plan. Predicted downstream recovery may not have a realistic basis.
- Any relaxation of basic requirements such as lower performance, etc.

## 5. EFFECT OF INCENTIVES ON TEST AND EVALUATION

Improper incentives can warp the proper conduct of the test and evaluation.

In demonstrations, the success criteria should be broader than simply hit or miss in a single given scenario. Otherwise, the entire program may be skewed to meet the requirements of the selected scenario to the detriment of testing a wider area of the performance envelope.

## 6. SOFTWARE TESTING

Test and evaluation should ensure that software products are tested appropriately during each phase.

Software has often been developed more as an add-on than as an integral part of the overall system. Software requirements need the same consideration as hardware requirements in the Validation Phase. Usual practices often do not sufficiently provide for testing the software subsystem concept. Facilities available to contractors for software development and verification are becoming increasingly critical to schedule and cost. Note that this topic is treated at greater length in Chapter II and in Annex A.

## 7. REQUIREMENT FOR TEST REHEARSALS

Test rehearsals should be conducted for each new phase of testing.

The purpose is to shake down the test plan, the instrumentation concept, and the data analysis plan. A secondary, but vital, purpose should be to provide training for the test participants. The pilot run should be scheduled and conducted in such a way that sufficient time will be available to make the necessary changes to the test as dictated by the results of the pilot run.

In the pilot run, particular attention must be given to the range safety aspects so that range safety officials do not destroy a good test because of previously undiscovered momentary deficiencies which might occur during the surveillance of the test article.

Simulation and other laboratory or ground testing should be conducted to predict specific test outcomes. The test run should of course be run to verify the test objectives. Evaluation of the simulation versus the actual test results will help to refine the understanding of the system.

## B. SCHEDULING

The following are checklist items contained in this section:

1. Building Block Test Scheduling
2. Component and Subsystem Test Plans
3. Phasing of DT&E and IOT&E
4. Use of Functional Milestones
5. Test Schedule Constraints
6. Requirements for Military Construction Program Facilities
7. Scheduling of Tests Using Government Furnished Equipment
8. Scheduling IOT&E to Include System Interfaces with Other Systems

1. BUILDING BLOCK TEST SCHEDULING

The design of the set of tests to demonstrate feasibility prior to DSARC II should be based on a building block concept.

High technical risk items should be tested early and subsequent tests should incorporate more and more of the hardware until the complete system concept has been demonstrated as feasible.

2. COMPONENT AND SUBSYSTEM TEST PLANS

Assure a viable component and subsystem test plan.

Studies show that almost all component failures will be the kind that cannot easily be detected or prevented in full system testing. All experience indicates that new systems will exhibit the "new system syndrome" and that the best return on test investment will come from applying substantial attention to component and subsystem level test effort. Detecting a subsystem or component failure only at the operational test level puts the cost of correcting such failures at the high end of an exponential cost curve.

3. PHASING OF DT&E AND IOT&E

In evaluating test plans, look favorably on phasing where the IOT&E is run in parallel with continued DT&E.

Problems that become apparent in the operational testing can often be evaluated much more quickly and more completely with the instrumented DT&E hardware. This is more attractive where the DT&E is performed with non-expendable hardware like airplanes.

In general, DT and OT plans and schedules must be rejected if they do not make provisions for the occurrence of failures. Plans should include time and money necessary for investigating test failures and making provisions for elimination of the cause before other similar tests take place. (However, see A-3.) Further, it is imperative that a percentage of the total tests (sorties, runs, trials, experiments) be allowed for retesting over and above the number required to successfully complete the program.

This percentage must be related to the probability of achieving success as opposed to failure.

4. USE OF FUNCTIONAL MILESTONES

System milestones should be flexible with respect to time.

In evaluating the adequacy of the scheduling as given by test plans, it is important that milestones be tied to the major events of the weapon system (meeting stated requirements) and not the calendar. The acquisition process should be based on the achievement of major milestones and sufficient time and resources allowed between these milestones. This flexibility must not be hampered by the contracting mechanism. Contractors should be required to demonstrate successful accomplishment of technical milestones before proceeding to the next phase of development.

5. TEST SCHEDULE CONSTRAINTS

The test schedule for the system should:

(a) Allow for a sufficient time between the planned end of demonstration testing and major procurement decisions so that there is a flexibility for modification of plans which may be required during the test phases of the program;

(b) Be evaluated relative to constraints imposed by:

- The number of test items available and the schedule interface with other systems needed in the tests, such as aircraft, electronics, missiles, etc.
- Support required to assist in the preparation, conduct of the tests and the analysis of test results;

(c) As stated previously in A-1, be adjusted to minimize the so-called T&E gap caused by a lack of hardware. Specifically, a test gap can result if funds are not applied until the results of IOT&E are known because of the required lead time for production planning, production facilities, and tool and production hardware.

6. REQUIREMENTS FOR MILITARY CONSTRUCTION PROGRAM FACILITIES

Some systems cannot be fully tested without Military Construction Program (MCP) facilities.

The long lead times to obtain authorization, appropriations, and to construct facilities can pace a program. Many steps and considerable time may be involved in getting facilities ready and test gear in place to start system tests.

If completion of DT&E and the operational testing requires the MCP facility, these matters must be considered in preparing and evaluating the test plan.

7. SCHEDULING OF TESTS USING GOVERNMENT FURNISHED EQUIPMENT

If there are GFE and other government commitments in the proposed contract, be concerned about the following:

(a) Can the gear with required performance be available when required?

(b) Can government supported facilities provide the assistance required at the time needed? If not, is it reasonable to construct the required facilities (test range, instrumentation, building, etc.)? If not, what alternatives are available?

(c) Avoid contract terms on fixed price contracts that vaguely commit the government. Do not include "Government support as required" or "test facilities will be made available when needed."

8. SCHEDULING IOT&E TO INCLUDE SYSTEM INTERFACES WITH OTHER SYSTEMS

Whenever possible, the IOT&E (as well as the FOT&E) of a weapon system should be planned to include other systems which must have a technical interface with the new system.

Thus missiles should be tested on most of the platforms for which they are programmed. Interfaces between systems should receive special attention.

## C. CRITERIA

The following are checklist items contained in this section:

1. Criteria for Critical Issues
2. Criteria for Competitive Testing
3. Criteria for Performance Demonstrations
4. Reliability Determinations in IOT&E
5. Expected Value of Testing

1. CRITERIA FOR CRITICAL ISSUES

In evaluating the initial DCP (or its equivalent documentation such as PMs), it is important to ensure that the tests to be conducted during the period from DSARC I to DSARC II address the major critical issues, especially those technological issues which are identified in the DCP.

By the end of the systems Definition Phase, test and evaluation should make certain that "test criteria" are established so there is no question as to what constitutes a test and what performance is to be attained. Each test should have a single objective if possible, and the objective should be simply stated. A plan for the conduct of the test and the data collection, reduction, and analyses must be in sufficient detail that one can readily evaluate the performance of the system and whether or not the test objective can be met. A relationship between the identified performance parameters and the test results should be established prior to the conduct of the test. Further, the set of objectives for each of the tests should be clearly related to the program objective as defined in the DCP. When this relationship is not clear, amplifying data should be required.

2. CRITERIA FOR COMPETITIVE TESTING

When competitive designs are under consideration, criteria for selection should be specified in advance, with critical issues identified for each design.

The DCP, or equivalent documentation, should include the evaluation criteria to be used for the selection of the final system design. They should be based on performance factors which are measurable through testing. A data collection and evaluation plan should be developed which will permit description of the range of acceptable performance for each factor.

3. CRITERIA FOR PERFORMANCE DEMONSTRATIONS

In designing contractually required demonstration tests upon whose outcome may depend large incentive payments, or even program continuation, it is essential to specify broader success criteria than simply hit or miss in a single given scenario.

If this is not done, the entire program may be skewed to meet the requirements of the selected scenario, to the detriment of exploring a wider area of the performance envelope. With too much weight attached to a go/no go outcome, temporary hardware, not designed for the final purpose, may be retained beyond the early stages of the program to enhance the probability of successful demonstration.

Demonstrations should be designed to measure overall performance, with statistical weighting to compensate for reduced probabilities of occurrences at edge values of condition parameters.

Contract requirements and incentives should not be weighted heavily on performance at extreme corners of the theoretical performance envelope unless there is a very high payoff for such performance, since excessive effort may be spent on obtaining it.

## 4. RELIABILITY DETERMINATIONS IN IOT&E

IOT&E can provide valuable data on the operational reliability of weapon systems which cannot be obtained through DT&E.

Apparent operator error failures and apparent random failures should be looked for in the operational tests and investigated to determine if serious problems are underlying reasons for the failures. Especially important is the procedure used to evaluate the operational reliability of the system as determined by the relatively small but significant amount of data obtained through IOT&E and the larger amounts of data on hardware design reliability collected through DT&E. Further, maintenance practices should be carefully studied to assess their impact on the observed operational reliability obtained through IOT&E.

Validation of system life cycle cost should be a primary objective of IOT&E. Inasmuch as procurement cost of any system is only the tip of the iceberg, other costs such as operation and maintenance will, over the life cycle, make up a larger portion of the cost to the taxpayer. Where inordinate expenditures for replacement of high-cost components, heavy operator manning requirements, or high maintenance man-hours per operating hour can be identified or forecast through IOT&E, this should be done. Where possible, such predictions should be made in quantitative terms.

## 5. EXPECTED VALUE OF TESTING

Operational testing is essential, but it is also expensive and time consuming.

Be sure in advance that the value received is worth its weight in not-delivered systems. Think in terms of:

(a) Involving operational groups in test planning and in establishing measures of effectiveness, so that the outcome of the tests will be accepted as being operationally significant.

(b) Determining whether the scope of the planned tests will provide sufficient data to justify any change at all in the eyes of potential users.

(c) Comparing the scope of proposed tests against checklists of issues frequently raised at major decision milestones, to assure that the data needed for such decisions will be forthcoming to the extent this is possible from testing alone.

(d) Recognizing in the formulation of test plans that major system decisions are judgments based on a wide range of qualitative considerations, rather than on statistical compilations, and that the outcome and limitations of operational tests must be comprehensive and meaningful to the decision makers as well as to the testing community.

## D. RESOURCES

The following are checklist items contained in this section:

1. Identification of Test Resources and Instrumentation Requirements
2. Requirements for Joint Service OT&E
3. Military Construction Program Facilities
4. Government Furnished Equipment
5. Instrumentation Packages for OT&E
6. Test Sample Sizes

1. IDENTIFICATION OF TEST RESOURCES AND INSTRUMENTATION REQUIREMENTS

Before DSARC II the test facilities and instrumentation requirements to conduct operational tests should be identified, along with a tentative schedule of test activities.

The applicability of existing test ranges and the adequacy of current facilities and instrumentation should be verified. Insofar as possible, alternative approaches (different ranges, etc.) and instrumentation improvements needed should be specified. Of prime importance are the constraints to be placed on the test because of the range and instrumentation. If range and instrumentation factors are found to cast significant doubt on the meaningfulness of the test data because of a lack of operational realism, the steps necessary to assure meaningful data should be identified and planned prior to DSARC II.

2. REQUIREMENTS FOR JOINT SERVICE OT&E

Joint service operational test and evaluation should be considered for those weapon systems which require new operational concepts involving other services.

Emphasis in the joint tests should include investigations of the impact on the effectiveness of the weapon system of such aspects as CCC, target acquisition, damage assessment, and countermeasures. If joint testing is recommended, an analysis of the impact of this type of demonstration on time and resources needed in the program and the additional resources needed to execute the joint tests should be conducted before DSARC II.

3. MILITARY CONSTRUCTION PROGRAM FACILITIES

Some systems cannot be fully tested without Military Construction Program (MCP) facilities.

As stated before, the long lead times to obtain authorization, appropriations, and to construct facilities can pace a program. Many steps and considerable time may be involved in getting facilities ready and test gear in place to start system tests.

If completion of DT&E and the operational testing requires the MCP facility, these matters must be considered in preparing and evaluating the test plan.

4. GOVERNMENT FURNISHED EQUIPMENT

<u>If there are GFE and other government commitments in the proposed contract, be concerned about the following:</u>

(a) Can the gear with required performance be available when required?

(b) Can government-supported facilities provide the assistance required at the time needed? If not, is it reasonable to construct the required facilities (test range, instrumentation, builting, etc.)? If not, what alternatives are available?

(c) Avoid contract terms on fixed price contracts that vaguely commit the government. Do not include "government support as required" or "test facilities will be made available when needed."

5. INSTRUMENTATION PACKAGES FOR OT&E

<u>The manner in which T&E instrumentation is used can be extremely important in determining the realism possible in the OT&E phases</u>.

The instrumentation package should be fixed early in the design phase of the development; it is difficult and costly to change thereafter. For this reason, instrumentation requirements must be specified early in the program and operational factors must be incorporated early.

6. TEST SAMPLE SIZES

<u>The primary basis for the test sample size is usually based on one or more of the following</u>:

- Analysis of test objectives
- Statistical significance of test results at some specified confidence level.
- Availability of test vehicles, items, etc.
- Support resources or facilities available
- Time available for the test program.

One should not hesitate to terminate a test prior to its completion when it becomes clear that the main objective of the test is unachievable (because of hardware failures, unavailability of resources, etc.), or that additional samples will not change the outcome and conclusions of the test.

## E. COSTS

The following are checklist items contained in this section:

1. Budgeting for Test
2. Funds for Correction of Faults Found in Testing
3. Component and Subsystem Test Plans

1. BUDGETING FOR TEST

The DCP and later budgeting documents should be regularly reviewed to ensure that there are adequate identified funds for testing, relative to development and fabrication funds.

A review of previous programs shows that testing funds and test articles have been postponed or eliminated to keep program costs in line as projected development requirements or costs have increased.

2. FUNDS FOR CORRECTION OF FAULTS FOUND IN TESTING

The DCP and later budgeting documents need careful scrutiny to ensure that there are adequate contingency funds to cover correction of difficulties at a level which matches the Industry/Government experience on such contracts. (Testing for difficulty without sufficient funding for proper correction results in band aid approaches which ultimately require correction at a later and more expensive time period.)

Discussions with industry representatives indicate almost universally an erosion process of contingency funds throughout the bidding and negotiation process. This fact has led to enormous financial difficulties to the contractors in "package procurement programs." Today there is a trend toward funding difficulties on Cost Reimbursement Contracts because contractors have been encouraged to be optimistic because of their low legal liability. Further, inadequate contingency funding is being carried by the government.

3. COMPONENT AND SUBSYSTEM TEST PLANS

Assure a viable component and subsystem test plan.

As previously stated, studies show that almost all component failures will be the kind that cannot easily be detected or prevented in full system testing. All experience indicates that new systems will exhibit the "new system syndrome," and that the best return on test investment will come from applying substantial attention to component and subsystem level test effort. Detecting a subsystem or component failure only at the operational test level puts the cost of correcting such failures at the high end of an exponential cost curve.

## F. ISSUES: Performance

1. Necessity for Ranges of Criteria
2. Effects of Incentives on Test and Evaluation
3. High Technical Risk Development
4. Proof of Performance on Major Critical Issues
5. Proof of Performance of Software
6. Proof of Performance of Human Factors Concepts

1. NECESSITY FOR RANGES OF CRITERIA

Analytic and empirical studies should be conducted prior to DSARC I to ensure that the range of critical performance characteristics has been specified.

Each performance characteristic so specified should be measurable through bench and laboratory or proving ground testing. The test design and the number of tests should be adequate to provide results with confidence limits compatible with the statements of desired characteristics. Testing in advanced development should be planned to explore performance characteristics over a broad range of environments so as to provide insight into system performance over the expected operational range and not just at a single point.

2. EFFECTS OF INCENTIVES ON TEST AND EVALUATION

Improper incentives can warp the proper conduct of testing and evaluation.

In reviewing contractually required demonstration tests upon whose outcome may depend large incentive payments, or even program continuation, it is essential to specify broader success criteria than simply success or failure in a single given scenario. If this is not done, the entire program may be skewed to meet the requirements of the selected scenario, to the detriment of exploring a wider area of the performance envelope. At the same time, contract requirements and incentives should not be based upon performance at extreme corners of the theoretical performance envelope unless there is a very high payoff of such performance since excessive effort may be spent in obtaining it.

3. HIGH TECHNICAL RISK DEVELOPMENT

When high technical risk is present, development should be structured around the use of prototypes designed to prove the system concept under realistic operational conditions before proceeding to engineering development.

It is good to take a risk; however, when an implied commitment to production is involved, the technology should be operationally proof tested prior to commencing Full-Scale Development. On the other hand, avoid the temptation of thinking that anything is "state-of-the-art" until it is working in the field.

4. PROOF OF PERFORMANCE ON MAJOR CRITICAL ISSUES

In evaluating the initial DCP (or its equivalent), it is important to ensure that the tests to be conducted during the period from DSARC I to DSARC II address the major critical issues, especially those technological issues which are identified in the DCP.

Each test should have a single objective if possible, and the objective should be simply stated. A plan for the conduct of the test and the data collection, reduction, and analysis must be in sufficient detail so that one can readily evaluate the performance of the system whether or not the test objective can be met. A relationship between the identified performance parameters and the test results should be established prior to the conduct of the test. Further, the set of objectives for each of the tests should be clearly related to the program objective as defined in the DCP. When this relationship is not clear, amplifying data should be required.

The design of the set of tests to demonstrate feasibility prior to DSARC II should be based on a building block concept, with high technical risk items being tested early and with subsequent tests incorporating more and more of the hardware until the complete system concept has been demonstrated feasible.

Also, if any subsystem is being tested as a complete assembly, it should be examined to ensure that it is truly state-of-the-art and has been previously proven.

5. PROOF OF PERFORMANCE OF SOFTWARE

Test and evaluation should ensure that software products are tested appropriately as described in Chapter II and Annex A.

As previously stated, software has often been developed more as an add-on than as an integral part of the overall system. Software requirements need the same consideration as hardware requirements in the Validation Phases. Usual practices often do not sufficiently provide for testing the software subsystem concept. Often the facilities available to contractors for software development and verification are critical to schedule and cost.

## 6. PROOF OF PERFORMANCE OF HUMAN FACTORS CONCEPTS

At an appropriate time in concept definition or Development Phase, T&E should authenticate the human factors concepts embodied in the proposed system design, examining questions of safety, comfort, appropriateness of man-machine interfaces, as well as the number and skill of the personnel required.

The numbers of personnel required should be validated against both operational and maintenance requirements. Testing early versions in the "human acceptability and compatibility" environment is extremely important. This will also help to validate the manning requirements.

## F. ISSUES: Operational Realism/General

The following are checklist items contained in this section:

1. Testing in Degraded Modes
2. Evaluation of Testing with Pre-Operational Equipment
3. Effect of Instrumentation on Test Realism
4. Joint Tests
5. Realism in Demonstrations
6. Realism of Maintenance and Repair in Testing
7. Operational Reliability Estimation in IOT&E
8. Effect of Observers on Test Realism
9. Justification for Realistic OT&E

1. TESTING IN DEGRADED MODES

The system concept and possible implementations must not hinge on the requirement for the system or subsystems to be finely tuned when the expected operational environment suggests that this will not be likely.

The system should degrade gracefully as a result of detuning caused from expected operational usage. If the capability to keep the system peaked is expected to degrade with operational use then tests should be conducted under the degraded conditions.

2. EVALUATION OF TESTING WITH PRE-OPERATIONAL EQUIPMENT

Results of tests conducted during exploratory development and which most likely have been conducted on brassboard, breadboard, or modified existing hardware should be evaluated with special attention to items such as:

(a) The packaging of the hardware may significantly affect the performance characteristics such that the suggested proof of validation is inconclusive.

(b) Scaling laws may invalidate the findings or introduce new technology problems.

(c) The laboratory type environment in which the hardware was tested may preclude the generation of data needed to validate that the concept and technology approach will be applicable to an operational environment.

(d) The tests may not include signals and noise sources representative of those that might be expected in an operational environment.

3. EFFECT OF INSTRUMENTATION ON TEST REALISM

The constraints to be placed on the test because of the range and instrumentation are of prime importance.

As previously stated, before DSARC II the test facilities and instrumentation requirements to conduct operational tests should be identified, along with a tentative schedule of test activities. The applicability of existing test ranges and the adequacy of current facilities and instrumentation should be verified. Insofar as possible, alternative approaches (different ranges, etc.) and instrumentation improvements needed should be specified. If range and instrumentation factors are found to cast significant doubt on the meaningfulness of the test data because of a lack of operational realism, the steps necessary to assure meaningful data should be identified and planned before DSARC II.

4. JOINT TESTS

Joint service operational test and evaluation should be considered for those weapon systems which require new operational concepts involving other services.

Emphasis in the joint tests should include investigation of the impact on the effectiveness of the weapon system of such aspects as CCC, target acquisition, damage assessment, and nominal types of countermeasures. If joint testing is recommended, an analysis of the impact of this type of demonstration on time and resources needed in the program and the additional resources needed to execute the joint tests should be conducted before DSARC I.

5. REALISM IN DEMONSTRATIONS

Demonstration and acceptance tests, as well as tests intended to evaluate performance under operational conditions, should always be conducted under conditions as close to those anticipated in practice as possible.

On the other hand, test conditions during development should be determined by the primary objectives of that test, rather than by more general considerations of realism, etc. Whenever a non-tactical, non-operational configuration is dictated by test requirements, the results of the tests should not be challenged by the fact that that configuration was not tactical or operational.

6. REALISM OF MAINTENANCE AND REPAIR IN TESTING

Prior to the decision to go into Full-Scale production of the weapon system, a complete technical/maintenance data package must be prepared and tested to ensure that the system can be maintained.

The testing of this package should be considered first as part of DT&E and then as part of the IOT&E of the system. Criteria for successful demonstration of this package should be established in both types of tests.

7. OPERATIONAL RELIABILITY ESTIMATION IN IOT&E

<u>IOT&E can provide valuable data on the operational reliability of weapon systems which cannot be obtained through DT&E.</u>

Factors such as operator error failures and apparent random failures should be looked for in the operational tests and investigated to determine if serious problems are underlying reasons for the failures. Especially important is the procedure used to evaluate the operational reliability of the system as determined by the relatively small amount of, but significant, data obtained through IOT&E and the large amounts of data on hardware design reliability collected through DT&E. Further, the maintenance practices should be carefully studied to assess their impact on the observed operational reliability obtained through IOT&E.

8. EFFECT OF OBSERVERS ON TEST REALISM

<u>Test conduct can be influenced by the actions of the observers and umpires.</u>

These people can provide important clues to the participants of operational suitability testing and in that way lessen the validity of the test. For example, in situations where air/ground duels are to be conducted, briefed observers who look in the direction of the aircraft, might inadvertently tip-off the direction of approach to the ground party in the duel. Similarly, concentrations of observers at a certain location may clue the aircrews where to search first for the ground targets.

9. JUSTIFICATION FOR REALISTIC OT&E

<u>Operational testing is essential, but it is also expensive and time consuming.</u>

Be sure in advance that the value received is worth its weight in not-delivered systems. Think in terms of:

(a) Involving operational groups in test planning and in establishing measures of effectiveness, so that the outcome of the tests will be accepted as being operationally significant.

(b) Determining whether the scope of the planned tests will provide sufficient data to justify any change at all in the eyes of potential users.

(c) Comparing the scope of proposed tests against checklists of issues frequently raised at major decision milestones, to assure that the data needed for such decisions will be forthcoming to the extent this is possible from testing alone.

(d) Recognizing in the formulation of test plans that major system decisions are judgments based on a wide range of qualitative considerations, rather than on statistical compilations, and that the outcome and limitations of operational tests must be comprehensive and meaningful to the decision makers as well as to the testing community.

## F. ISSUES: Operational Realism/Personnel

The following are checklist items contained in this section:

1. Use of Appropriate Personnel During Test
2. Training Personnel for Tests
3. User Participation in Testing
4. Test Planning Personnel Qualifications
5. Continuity of OT&E Personnel in Test Planning
6. OT&E Pre-Test Training and Transition

1. USE OF APPROPRIATE PERSONNEL DURING TEST

Testers, evaluators and operators have quite different backgrounds and needs which affect the T&E of the weapon system.

Each has a different approach which has merit and utility at almost all points in the T&E program. A mix of these types is needed throughout the program. Early in the program, the lead emphasis should be from the tester, shifting to the evaluator and finally the operator, but at all times all parties and their needs should be coordinated.

2. TRAINING PERSONNEL FOR TESTS

Training plans and certification plans for test personnel should be established early in the Full-Scale Engineering Development Phase. Errors by test personnel are usually expensive and often cloud the reason for test failures.

3. USER PARTICIPATION IN TESTING

It is imperative that the Independent Test Agency participate in all of the T&E phases to ensure that the user needs are represented in the development of the system concept and hardware.

Initially, the Independent Test Agency should play an advisor role during the feasibility and engineering testing, and gradually take over leadership in the conduct of the testing program as it becomes more and more operational. This should facilitate the necessary communication and interaction between developing and user commands--especially needed during the DT&E and IOT&E phases.

4. TEST PLANNING PERSONNEL QUALIFICATIONS

The test director and/or key members of the test planning group within the project office should have significant T&E experience.

If the requisite experience does not exist at the appropriate levels within the project office, test plans may be based on too shallow or too naive a conception of the role and potential utility of the T&E process. All too often, key test personnel are assigned to T&E slots with little prior exposure to T&E or its management, and with inadequately experienced support as well. The test planning group should have personnel experienced in engineering testing, development testing and operational testing. This experience should be available very early and all efforts should be made to encourage these people to remain with the weapon system project office through the T&E phases of the program.

5. CONTINUITY OF OT&E PERSONNEL IN TEST PLANNING

The planners and evaluators for the OT&E of the production equipment can do a better job if they are initially involved in planning and conducting the IOT&E.

The program plan should be reviewed to ensure that the FOT&E people are identified for IOT&E participation and that the personnel system of their service retains identity of these people for use in planning, conducting, and evaluating FOT&E which may not be run until a year or two afterwards.

6. OT&E PRE-TEST TRAINING AND TRANSITION

In the initial conduct of OT&E, the participants should be given a period of time to dry run the scenario and to shake-down the instrumentation and the overall operation before key resources are expended in tests for record.

In a properly planned OT&E program, the people will have completed proper individual training on the new system but the operational organization will not be able to conduct full unit training until the hardware, software, and support equipment are on hand. After the period when the unit is qualified as being operationally ready, it would be ready for assignment to OT&E testing.

## F. ISSUES: Operational Realism/Threat and Environment

The following are checklist items contained in this section:

1. Offense/Defense Environment
2. Joint Service Operational Testing

## 1. OFFENSE/DEFENSE ENVIRONMENT

The OT&E plan should include offense/defense engagements in the environments in which the new system is expected to operate.

Offense/defense testing may be addressed in several phases, such as:

(a) One-on-one testing against existing U.S. counter systems and available simulators of the assumed threat.

(b) One-on-one testing against advanced U.S. technology which may be representative of a logical threat.

(c) Multiple vehicle testing in a multiple threat environment.

(d) Comparative testing of the new system with existing systems to estimate the increased capability.

Test range and resource requirements should be estimated, and, if inter-service testing is contemplated, preliminary plans for such testing should be coordinated with the cooperating service.

## 2. JOINT SERVICE OPERATIONAL TESTING

Joint service operational test and evaluation should be considered for those weapon systems which require new operational concepts involving other services.

As stated twice before, emphasis in the joint tests should include investigation of the impact on the effectiveness of the weapon system of such aspects as CCC, target acquisition, damage assessment, and nominal types of countermeasures. If joint testing is recommended, an analysis should be conducted before DSARC I of the impact of this type of demonstration on time and resources needed in the program and the additional resources needed to execute the joint tests.

## G. REPORTING

The following are checklist items contained in this section:

1. Feedback of Test Results
2. Data Reporting Format
3. Data Collection on Subsystems and Components
4. Provision of Data for Modeling of Alternative Conditions and Scenarios

1. FEEDBACK OF TEST RESULTS

A good test program makes provisions for feedback of test results, during conduct of the testing, so as to influence:

(a) Course of the T&E program (test director, program manager).

(b) Trade-off decisions between modifying the system design and relaxing the operational requirements (program manager, operating/supporting commands, HQ).

(c) Missions, employment doctrine, tactics and constraints, tactical organization, etc. (operating command, operational units).

(d) Parts provisioning.

2. DATA REPORTING FORMAT

Establish a T&E reporting format for the program--insist on its use throughout the duration of the program.

Use this to:

(a) Establish a closed loop reporting and resolution process which assures that each test failure at every level is corrected by appropriate action, i.e., redesign, procurement, retest, etc.

(b) Establish a program-to-program crosstalk relative to T&E problems and approaches.

3. DATA COLLECTION ON SUBSYSTEMS AND COMPONENTS

When developing, testing and evaluating the various subsystems (and systems) of non-expendable weapon systems, each component of the systems should be numbered and a performance history kept which allows an analysis of that component's performance with respect to reliability, maintainability, availability, etc.

An analysis of failure modes should be made in advance so as to relate test results to the operational capability of the system when in a degraded condition.

4. PROVISION OF DATA FOR MODELING OF ALTERNATIVE CONDITIONS AND SCENARIOS

Develop techniques and system range instrumentation to provide the type of data in the proper form to allow economic, analytical, and mechanical simulation for alternate scenarios and combinations.

## Annex A

## SOFTWARE

## SOFTWARE

### A. INTRODUCTION

This annex is intended to provide guidelines for program managers and program monitors in tracking the development of computer programs essential to the functioning of weapon systems. The purpose is to ensure that the software development is scheduled, performed, and tested with the same degree of attention to quality, schedule, and cost as is the hardware part of the system. It is assumed that the program manager's office will include in its staff experienced professionals who are skilled in programming design, implementation, testing, and support, and that the contractor or service developer will bring to bear the necessary talents for excellence in program design, implementation, testing, and support. It is also assumed that the program manager and his staff will provide sufficient information on overall system and software objectives to enable the developer to prepare two essential documents prior to development of test plans. These essential documents are the Program Functional Description and the Program Logic Description.

A number of checkpoints at which developer and program manager achieve agreement on critical issues are necessary to accomplishment of a successful development. The following list is a suggestion for the timing and critical issues to be covered at the specific points.

Checkpoint 1: Timing: At the start of the development.

Critical issues:

1. User/developer agreement in statement of and interpretation of requirement.
2. Establishment of the changes policy.
3. Establishment of the development plan.
4. Determine source of hardware required for software development.

Checkpoint 2: Timing: Upon completion of Program Functional Description.

Critical issues:

1. Reaffirm user statement of requirements.
2. Identification of potential problems in interfaces,

performance, diagnostics, human factors, standards compliance.

3. Adequacy of resources.

4. Development schedules.

Checkpoint 3: Timing: Upon Completion of Program Logic Description.

Critical issues:

1. Documentation of proposed data flow, logic flow, and program organization to implement each required function.

2. Determination of interfaces between segments of the program.

3. Reaffirm user statement of requirements.

4. Adequacy of computer facilities to accommodate program.

Checkpoint 4: Timing: Upon completion of test plan.

Critical issues:

1. Completeness and consistency of test plan with Program Functional Description and Program Logic Description.

2. User approval of test plan/criteria.

3. Credibility of schedule and cost planning.

Checkpoint 5: Timing: After critical functions in the program have been programmed.

Critical issues:

1. Verification in coordination with the user that critical functions have been completely and adequately covered by programming.

Checkpoint 6: Timing: After all testing is complete.

Critical issues:

1. Verification in coordination with user that the program meets all functional requirements.

2. Verification that program meets all specifications and user requirements.

3. User acceptance of test results.

4. Verification that program documentation is acceptable.

5. Verification that program support is feasible and plans for support are complete. (Support includes distribution, installation, training, publications, corrections to programs, updating of programs, development of field tests for user, etc.)

This list of checkpoints is intended only as a basic outline, leaving unsaid many details on procedures, working arrangements, record keeping, scheduling, etc. Likewise, it makes no attempt to provide guidance to programmers inasmuch as developers will have their own design methods and review procedures.

Testing, however, is the prime concern of the Task Force, and the following contains guidance on developing test plans. In what follows, not all items discussed may be applicable to every system. Furthermore, it is not comprehensive. Some systems, because of their nature, may have additional requirements that are not foreseen here. Implementation of the test plan assures that the system is satisfactorily tested.

Unit testing, a necessity in the testing of any system, is not presented in this document. This is the testing by a programmer of his code before incorporating it into the system. Procedures should be established to ensure that this testing is done exhaustively.

## B. TEST PLAN OVERVIEW

The test plan must involve two major elements. The first is the design of the test cases. The system specifications form the basis for derivations of an exhaustive list of the functional variations. As the list is developed, test cases are designed to exercise each variation. A matrix of test cases, versus variations, provides a means of measuring the extent of coverage.

The second element of the approach is measurement. Unexecuted code (functions) must be detected and exposures evaluated. The test streams may then be expanded to cover those exposures.

Goals pertaining to the percentage of variations to be tested and the percentage of conditional branches executed should be established. They should be at a level which will assure the program manager that his software has been adequately tested. Completion of the testing effort would then be determined by achievement of the goals, not by schedules.

An integral part of the test plan must be detailed development and testing schedules. Each test plan must include a discussion of how the following areas will be tested:

- Reliability/Availability--the objective is to eliminate product incidents. This means that no software errors will result in reinitialization.
- Serviceability/Maintainability--provide for effective problem determination, problem diagnosis, and repair.
- Compatibility--the ability of a user to transfer from one program to another and continue to execute the jobs he has been executing.
- Usability--evaluate human factor characteristics.
- Capability--the ability of the program to function at various levels of stress.
- Security/Integrity--the ability of the program to protect data.
- Publications--the examples, limits, and externals specified in the publications are accurate and executable.

## C. TEST PLAN CHECKLIST

Nature of Development Activity

Dependencies & Interfaces

- Software
- Hardware

Identification of Variations

Major Testing Areas

- Function
- Environmental Testing
- Configuration Testing
- Compatibility Testing
- Limits Testing
- Error Messages & Conditions
- Publications Examples
- Recovery Testing

Performance Testing

Stress & Load Testing

Additional Testing Considerations

- Reliability/Availability
- Serviceability/Maintainability
- Usability
- Security/Integrity

Test Criteria

Entry Criteria
Exit Test Cases
Exit Criteria

D. TEST PLAN OUTLINE

1. Nature of Development Activity

Give a brief abstract of the nature of the development activity and the approximate size of the effort in terms of the number of modules affected or the amount of code required.

Include copy of description or a reference thereto and Checkpoint Plan documentation pertinent to the test plan, e.g., development schedule. If these documents do not contain the names of new/changed modules, include the names here.

2. Dependencies and Interfaces

a. Hardware

- Identify any dependencies on hardware that are not available at the coder's location.
- Identify commitments to obtain this hardware.
- Identify any unique critical dependencies upon hardware that are available at the coder's location and contingency plans in the event of nonavailability.
- Identify any hardware standards to include communication interfaces, applicable to this development.

b. Software

- Identify all dependencies on software that are not available at the coder's location. Include dependencies on other products and on drivers.
- Identify all new interfaces with other parts of the product or include a copy of the specifications that contain these.
- Identify commitments to obtain required software in sufficient time to adequately test interactions before integration.
- Identify significant internal development checkpoints.
- Identify any software standards applicable to the development.
- Identify standard data elements and code applicable to this development.

3. Identification of Variations

Identification of all syntactical and semantic variations stated in the Programming Functional Specifications. These variations are all candidates for test situations.

4. Major Testing Areas

For each of the following areas (or others as applicable) indicate the extent of testing planned, the origin and format of the test cases, and the procedures and tools to be used in conducting the tests. Also indicate where test cases are planned to cover two or more areas with the same test cases. In the case of previously released products, plans for testing the new code in any area should incorporate the plans for testing maintenance changes for that product which are scheduled for the same time period.

a. Function Testing

Verification that the specified functions match the programmed functions. This encompasses the following areas of testing:

- Programming Function Specification Testing--verification that the explicit functional specifications have been correctly implemented. Error injection techniques are recommended, where applicable, rather than simulation techniques.

- Programming Logic Specification Testing--verification that the explicit logic specifications have been correctly implemented.
- Interference Testing--verification that all programmed functions have been fully specified.

b. Environmental Testing

Verification by means of both test cases and procedures that the system operates in a realistic environment (i.e., the way that it is intended for a user to use it). It should cover such areas as:

- Running at peak or near peak load conditions for a sustained period of time.
- Utilization of such hardware configurations as are available.
- Testing on a driver.

c. <u>Configuration Testing</u>

Verify that the program operates within the hardware and software systems that support it.

- <u>Hardware Configuration</u>
  - Should exercise the hardware-dependent code.
  - Should exercise the code on various hardware configurations to verify that there are no hidden hardware dependencies.
- <u>Software Configuration</u>

  Verification that the function is viable in the supported software environments, e.g., sequential scheduling, multiprocessing, multiprogramming, etc.

d. <u>Compatibility Testing</u>

Verify that the program is consistent with any other program(s) with which it claims compatibility. It should cover such areas as:

- Previous versions of the same program.
- Other design levels of the same program.

e. <u>Limits Testing</u>

Verify that the program limits are correctly stated. The program should be tested outside of the limit, at the limit, and within the limit. This testing should include:

- <u>External Limits</u>
  - Verification of capacity, i.e., the quantity of input permissible under various storage levels.
  - Verification of the quantitative constraints stated in the functional specifications, e.g., the size of a record, depth of nesting, number of characters in an identifier; e.g., design point.
- <u>Internal Limits</u>

  Verification of internal limits, e.g., table sizes, queue entries, etc.

f. <u>Error Message and Error Condition Testing</u>

Verify that the error handling facilities of the program operate as stated and that these facilities are sufficient for the errors that occur.

- Force every error message and verify the accuracy and clarity of each. If the same error message appears for more than one error or can appear at significantly different times in the execution of the product, then these situations should also be covered.
- Plans for introducing various error conditions, for example:
  - Operator errors
  - Source language errors
  - Hardware failures
- Verification of interfaces with error handling routines.
- Provide a list of all new/changes messages and completion codes.

g. <u>Publications Example Verification</u>

Verify the validity of publications, e.g., figures in the storage examples, and tables concerning function(s) appearing in program documentation.

- Program documentation verification should include such things as:
  - Sample programs
  - Sample procedures
  - Examples
- Provide a list of all new/changes publications.

h. <u>Recovery Testing</u> (if applicable)

Verify that the Recovery Specifications are met under all environments. This should include the following:

- Verify proper creation and maintenance of the Recovery Environment.
- Simply stated, this requirement is to ensure that the proper recovery routine gains control at the proper time. This may be affected by the following four factors, each of which must be verified:
  - Verify that the correct recovery type was established.
  - Verify that proper conventions are observed.
  - Verify that the required parameters are effective on the recovery routine exits.
  - Verify that all routines which make a recovery routine known cancel that recovery routine before returning to caller.

- Exercise recovery code for all error types.
- Exercise recovery code under all entry conditions.
- Exercise recovery code under all critical interface situations.

5. Performance Testing

Identify how performance specifications will be verified.

6. Stress and Load Testing

Identify to what extent the program will be run at peak or near peak load over an extended period of time.

7. Additional Testing Considerations

For each of the following areas that are applicable, include a discussion of how the topic will be tested:

a. Reliability/Availability

The objective is to eliminate program incidents. This means that no software errors will result in reinitialization.

b. Serviceability/Maintainability

Provide for effective problem determination, problem diagnosis, and repair.

c. Security/Integrity

The code must conform to the specification.

8. Test Criteria

Select criteria to be considered necessary for entry into the testing phase and sufficient for exit from the testing phase.

a. Entry Criteria

List what criteria must be met before this testing phase will begin.

b. Exit Test Cases

List any test cases that are required to be successful before exit.

c. Exit Criteria

List the criteria that have been selected as being required for exiting the test phase.

# Annex B

# THE TEST AND EVALUATION GAP

## THE TEST AND EVALUATION GAP

Figure 1 illustrates some of the typical factors involved in the Test and Evaluation Gap problem. The chart shows key events and phases after the go-ahead for full-scale development, which occurs as a result of a favorable DSARC (II) decision. Typical R&D phasing is shown, where the first year or so is used in designing and building the initial test hardware. The subsystems then move into engineering tests, including R&D qualification tests. In the second and third year the system tests are conducted. Some Military Preliminary Evaluations (MPEs) occur early. IOT&E tests would be conducted after the R&D system demonstrated adequate adherence to the contract performance specifications.

If the IOT&E is reasonably successful and the service only then requests and obtains production authority for equipment to be used in OT&E, there will be a delay before production hardware is available because of the production tooling and production hardware lead time. To avoid the gap, depending upon the calendar time of the DSARC and the annual DoD budget submission and congressional defense, limited production funds would have to be defended a minimum of about 8 months prior to the major production decision. With less fortunate phasing, the budgeting lead time might be 4 to 6 months longer. Note on the Figure that this would require defense of the limited production program before the completion of the R&D system tests.

The limited production would normally be used by the first operational unit or the evaluation unit to do unit training and to work up to operational readiness for follow-on OT&E with production hardware. If there were no limited production the T&E gap would last for about 2 years, from the completion of IOT&E to the initiation of follow-on OT&E.

As illustrated in Figure 1, under GAP solution, if it were decided at the onset of the full-scale development that an additional phase of OT&E were to be pursued during what was formerly a gap period, then funds for gap filler test hardware and resources would have to be defended within about a year after the R&D go-ahead. The funds would have to be committed for long lead time items early enough so that the gap filler hardware, which would evolve from R&D to production configuration, would be available initially

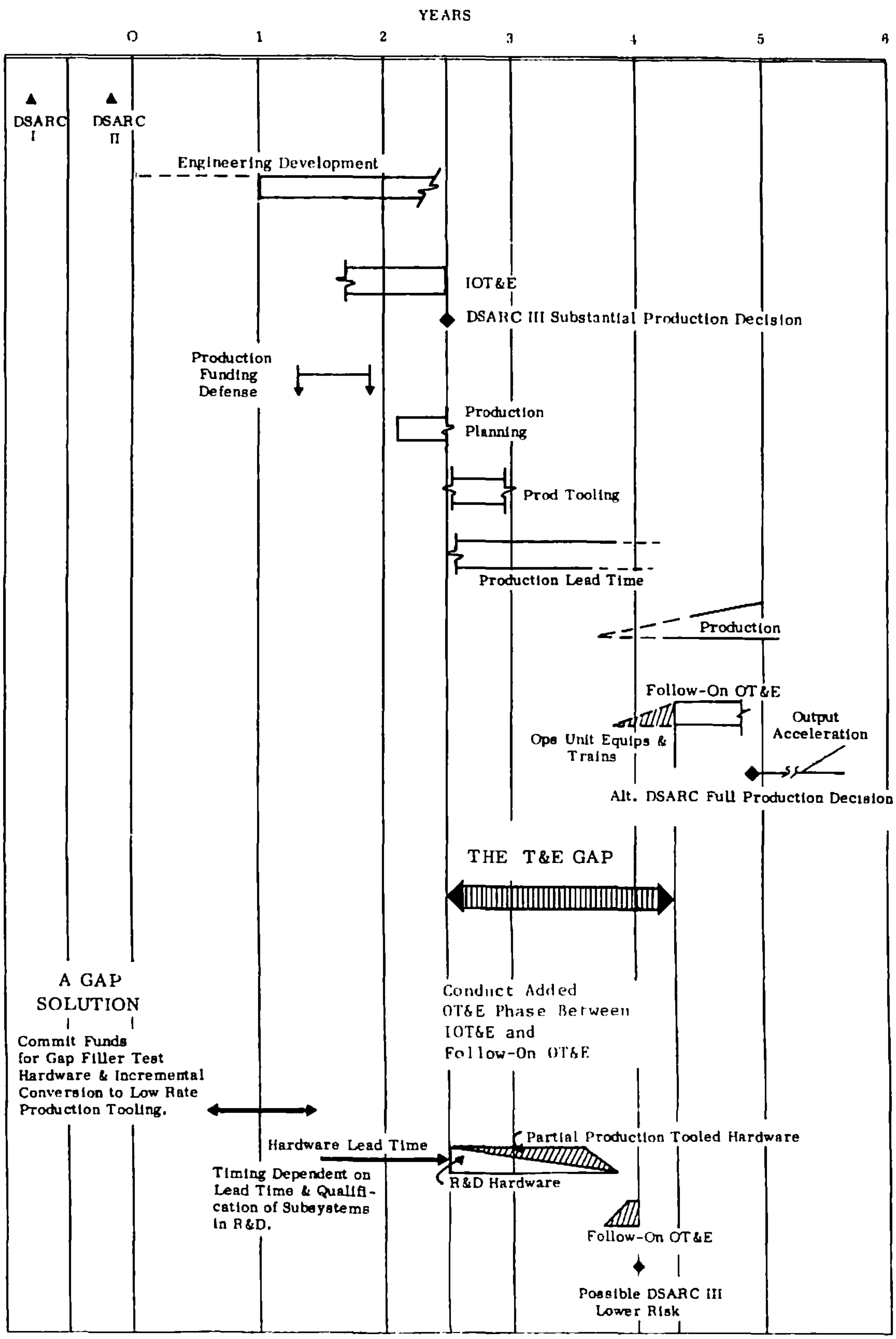


Figure 1. TYPICAL TEST AND EVALUATION GAP

at the end of the IOT&E. This additional OT&E phase would provide an additional year or two of operational experience before the major production output, thus providing a valuable opportunity to find and fix problems early, probably with R&D effort, hence minimizing costly modification programs which might be necessary if major production output followed a T&E gap. In addition, if the initial operations unit conducted this additional OT&E phase, the unit training would be accomplished and the unit should be ready to conduct follow-on OT&E as soon as the initial production hardware was available; hence, the initial operational capability (IOC) could be advanced several months. Certainly, the added years of experience during the former gap period should make the true capability at IOC much more effective.

It should be noted that the alternative of simply allowing the gap to exist, may be preferred when the effort to reduce the gap would require the commitment of a very large percentage (or amount) of the expected program cost before T&E assurance of a successful product could be obtained. Also, non-expendable system acquisition programs, such as aircraft developments, can continue to fly the R&D hardware during the gap period, but the stop and go in the building of aircraft is costly and key OT&E issues, such as reliability of production equipment, could not be addressed.

In summary, the T&E gap between IOT&E and follow-on OT&E is costly because inertia in the program is lost; government, contractor and subcontractor manpower are cut back and then in a short time built up again; valuable time is lost which could be used for perfecting and learning to use the system; faults not discovered early can be more costly to fix after production acceleration; and the true operational capability data is delayed. The problems in closing the gap are that funds for additional hardware must be defended before the R&D program will have shown much progress as an operating system, and more funds are required for the program prior to the major production decision.

## Appendix A

TASK FORCE - TERMS OF REFERENCE

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D C 20301

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Study of Past Procurement

I have asked Dr. Eugene Fubini to form a Task Force which will undertake a thorough analysis of a number of past system acquisition programs to enhance our understanding of the role which test and evaluation should have had in the identification of their problems and to make recommendations for the role of test and evaluation in future programs. I wish this Task Force to be established as a part of the Defense Science Board.

A copy of my letter to Dr. Fubini with the Terms of Reference for this study is attached. Lt.Gen. Alfred D. Starbird (Ret), Deputy Director (Test and Evaluation), ODDR&E, is the responsible deputy, and Mr. Howard Kreiner, Civilian Staff Assistant, Office of Assistant Director (Strategic and Support Systems Test and Evaluation) is the staff action officer for this Task Force.

John S. Foster, Jr.

Attachment
Ltr to Dr. Fubini

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

14 Nov 1972

Dr. Eugene G. Fubini
Suite #816
1411 Jefferson-Davis Highway
Arlington, Virginia 22202

Dear Gene:

In the past few years there have been a number of reviews and studies of past and on-going weapons system acquisition programs, looking for means of avoiding or overcoming problems such as cost and schedule overrun, and system deficiencies in performance, reliability, and maintainability. Test and Evaluation activities have been looked at peripherally during some of these reviews, and some useful results have been obtained.

However, there has not been a major effort to investigate the possibility that effective testing could have resulted in earlier discovery and action on system problems.

I believe that a more complete investigation of representative programs would enable us better to understand how to improve our test and evaluation activities, where to concentrate more heavily and how to give our test and evaluation activities their highest potential payoff.

To conduct this investigation, I propose to establish a Task Force under your Chairmanship as a part of the Defense Science Board. I request that you assemble a select group to serve on the Task Force, to conduct the investigation of a group of specific programs. Please select the programs for study in coordination with Lt. Gen. A. D. Starbird (Ret.), my Deputy for Test and Evaluation. General Starbird will provide a full time staff member to your Task Force, and arrange for additional professional staff assistance through a contractor to be selected.

Your Task Force should conduct its investigations so as to establish for each program:

a. Whether the program had cost, schedule, or performance difficulties; from what specific aspects of the program these difficulties arose; and when the difficulty first became apparent (e.g., during design verification testing, acceptance testing, operational testing, or after deployment).

b. For each program and specific difficulty, was the discovery of the problem as early as reasonably could be expected? If not, what additional test measure reasonably could have been taken that might have found the difficulties? What test changes in the testing of future similar programs would appear warranted?

c. Based on the analysis of the entire group of programs, what areas and what potential problems should we examine more thoroughly and through what type and phase of testing? Further, are there areas in which excessive testing has been or is being carried out?

I expect that a year will be needed to address these questions. However, during this year we will work directly and closely with you in order to insure that the Task Force is working on the most important issues and that the Department is getting full benefit from early results of the Task Force's study.

Sincerely,

John S. Foster, Jr.

Enclosures
Memo for Chairman, DSB
Ltr for Prosp Task Force Mbr
& Distr List

# Appendix B

DOD DIRECTIVE 5000.3 TEST AND EVALUATION

January 19, 1973
NUMBER 5000.3

DDR&E

# Department of Defense Directive

SUBJECT Test and Evaluation

Refs.: (a) DoD Directive 5000.1, "Acquisition of Major Defense Systems," July 13, 1971
(b) DepSecDef multi-addressee memorandum, "Conduct of Operational Test and Evaluation," February 11, 1971 (hereby cancelled)
(c) DepSecDef multi-addressee memorandum on the subject of the role of DDR&E in test and evaluation as related to the DCP System, April 21, 1971 (hereby cancelled)
(d) DepSecDef multi-addressee memorandum, "Test and Evaluation in the System Acquisition Process," August 3, 1971 (hereby cancelled)

## I. PURPOSE

This Directive establishes policy for the conduct of test and evaluation by the Military Departments and Defense Agencies (hereinafter referred to collectively as "DoD Components") in the acquisition of defense systems (Sections III through VI). In addition, it codifies the responsibilities of the Deputy Director of Defense Research and Engineering, Test and Evaluation (DD(T&E)), which were previously promulgated by references (b), (c), and (d)(Section VII).

## II. CANCELLATIONS

References (b), (c), and (d) are hereby superseded and cancelled.

## III. SCOPE AND APPLICABILITY

The provisions of this Directive encompass major programs of defense systems acquisition as designated by the Secretary of Defense (described in Section II., of reference (a)) and apply to all DoD Components that are responsible for such programs. In addition, it provides principles to be applied by the DoD Components in their acquisition of Defense Systems that do not fall in the "major acquisition programs" category.

## IV. POLICIES AND PRINCIPLES

### A. General.

1. Test and evaluation shall be commenced as early as possible and conducted throughout the system acquisition process as necessary to assist in progressively reducing acquisition risks and in assessing military worth.

2. Acquisition schedules will be based, inter alia, upon accomplishing test and evaluation milestones prior to the time that key decisions which would commit significant added resources are to be made.

3. Before the initiation of development of a new system, test and evaluation using existing systems, or modifications thereto, may be appropriate to help define the military need for the proposed new system and to estimate its military utility. Determination of military worth, need, and utility will be accomplished in accordance with other DoD directives.

4. All test and evaluation activities shall consider environmental issues and provide assessments for review as early as possible in the test planning cycle. (See DoD Directive 6050.1.)

### B. Development Test and Evaluation (DT&E).

DT&E is that test and evaluation conducted to: demonstrate that the engineering design and development process is complete; demonstrate that the design risks have been minimized; demonstrate that the system will meet specifications; and estimate the system's military utility when introduced. DT&E is planned, conducted, and monitored, by the developing agency of the DoD Component, and the results thereof are reported by that agency to the responsible Military Service Chief or Defense Agency Director.

1. DT&E shall be started as early in the development cycle as possible and include testing of component(s), subsystem(s), and prototype or preproduction model(s) of the entire system. Compatibility and interoperability with existing or planned equipments and systems shall be tested.

2. During the development phase following the Program Initiation Decision (Milestone I), adequate DT&E shall be accomplished to demonstrate that technical risks have been identified and that solutions are in hand.

3. During the Full-Scale Development phase and prior to the first major production decision, the DT&E accomplished

shall be adequate to insure: that engineering is reasonably complete; that all significant design problems (including compatibility, interoperability, reliability, maintainability, and logistical considerations) have been identified; and that solutions to the above problems are in hand.

4. For those systems which have a natural interface with equipment of another Component or may be acquired by two or more Components, joint DT&E may be required. Such joint testing will include participation and support by all affected Components as appropriate.

C. Operational Test and Evaluation (OT&E). OT&E is that test and evaluation conducted to estimate the prospective system's military utility, operational effectiveness, and operational suitability (including compatibility, interoperability, reliability, maintainability, and logistic and training requirements), and need for any modifications. In addition, OT&E provides information on organization, personnel requirements, doctrine, and tactics. Also it may provide data to support or verify material in operating instructions, publications, and handbooks. OT&E will be accomplished by operational and support personnel of the type and qualifications of those expected to use and maintain the system when deployed, and will be conducted in as realistic an operational environment as possible. OT&E will normally be conducted in phases, each keyed to an appropriate decision point. During Full-Scale Development OT&E will be accomplished to assist in evaluating operational effectiveness and suitability (including compatibility, interoperability, reliability, maintainability, and logistic and training requirements). OT&E will be continued as necessary during and after the production period to refine these estimates, to evaluate changes, and to re-evaluate the system to insure that it continues to meet operational needs and retains its effectiveness in a new environment or against a new threat.

1. In each DoD Component there will be one major field agency (or a limited number of such major field agencies) separate and distinct from the developing/procuring command which will be responsible for OT&E and which will:

   a. Report the results of its independent test and evaluation directly to the Military Service Chief or Defense Agency Director.

   b. Recommend directly to its Military Service Chief or Defense Agency Director the accomplishment of adequate OT&E.

   c. Insure that the OT&E is effectively planned and conducted.

2. In addition, each DoD Component will provide within its immediate headquarters staff a full-time, strong, focal point organization to assist the independent OT&E field agency and to keep its Military Service Chief or Defense Agency Director fully informed as to needs and accomplishments.

3. Operational testing should be separate from development testing. However, development testing and early phases of operational testing may be combined where separation would cause delay involving unacceptable military risk, or would cause an unacceptable increase in the acquisition cost of the system. When combined testing is conducted, the necessary test conditions and test data required by both the DoD Component developing agency and OT&E agency must be realized. In addition, the separate Component OT&E agency must: insure that the combined test is so planned and executed as to provide the necessary operational test information; participate actively in the test; and provide separate evaluation of the resultant operational test information.

4. Acquisition programs will be so structured that at least an initial phase of operational test and evaluation (IOT&E) will be accomplished prior to the first major production decision adequate to provide a valid estimate of expected system operational effectiveness and suitability (including compatibility, interoperability, reliability, maintainability, and logistic and training requirements). Pilot production items will be employed for IOT&E wherever practicable. Prototypes, if they are reasonably representative of the expected production items, may be employed, where there otherwise would be delay involving unacceptable military risk or unacceptable increased acquisition costs.

5. For more complex systems, additional phases of OT&E may be required and performed with pilot or preproduction items subsequent to the first major production decision but prior to the availability of first production items. When production items are available in sufficient quantity, follow-on phases of OT&E adequate to meet the full objective outlined above will be accomplished by the appropriate DoD Component's independent OT&E agency.

6. For those systems which have a natural interface with equipment of another Component, or may be acquired by two or more Components, joint OT&E will be conducted where required. Such joint testing will include participation and support by all affected Components as appropriate.

D. Test and Evaluation for Major Ships of a Class. The long design, engineering, and construction period of a major ship will normally preclude completion of the lead ship and accomplishment of test thereon prior to decision to proceed with follow ships. In lieu thereof, successive phases of DT&E and OT&E will be accomplished as early as practicable at test installations and on the lead ship so as to rapidly reduce risks and thereby minimize the need for modification to follow ships.

1. When combat system complexity warrants, there will be constructed a combat system test installation wherein the weapon, sensor, and information processing subsystems are integrated through their interfaces in the manner expected in the ship class. Adequate initial DT&E and OT&E of the integration of those subsystems will be accomplished thereon prior to the first major production decision on follow ships. To the degree practicable first generation subsystems will have been approved for service use prior to the initiation of integrated operational testing. Where subsystems cannot be service approved prior to the initial operational testing, their integration will be tested at the test site installation as early as possible in their acquisition cycle.

2. For new ship types incorporating major technical advancements not earlier proven in hull or non-nuclear propulsion design, a prototype incorporating these advancements will be employed. If the major technological advancements are contemplated in only some features of the hull or non-nuclear propulsion design, the test installation need incorporate only the applicable new features. Adequate test and evaluation on such prototype will be completed prior to the first major production decision on follow ships.

3. The prototyping of Navy nuclear propulsion plants will be accomplished in accordance with the methods in use by the Atomic Energy Commission. Construction of the lead and follow ships will be done in the sequence now being used.

4. For all new ship classes, continuing phases of OT&E on the lead ship will be conducted at sea as early in the acquisition process as possible for specified systems or equipments and, if required, full ship operational evaluation to the degree feasible.

5. A description of the subsystems to be included in any test site or test prototype, the schedules to accomplish test and evaluation, and any exceptions to the above policies will be set forth in the initial and any subsequent DCPs and approved by the Secretary of Defense.

E. Test and Evaluation for One-of-a-Kind Systems. For one-of-a-kind systems, or systems involving procurement of only a very few over an extended period, the principles of DT&E of component(s), subsystem(s) and prototype or first production model(s) of the entire system will be applied. Compatibility and interoperability with existing or planned equipments will be tested. OT&E will be conducted as early as possible by the OT&E agency as necessary to provide a valid estimation of operational suitability and effectiveness.

F. Production Acceptance Test and Evaluation (PAT&E). PAT&E is test and evaluation of production items to demonstrate that the items procured fulfill the requirements and specifications of the procuring contract or agreements. It is the responsibility of each DoD Component to accomplish the necessary PAT&E throughout the production phase of the acquisition process.

G. Integrated T&E Plans. The DoD Component will prepare as early as possible in the acquisition process, and prior to initiation of Full-Scale Development, an overall test and evaluation plan to identify and integrate the effort and schedules of all T&E to be accomplished and to insure that all necessary T&E is accomplished prior to the key decision points. This plan will be kept current by the DoD Component.

H. Defense Systems Acquisition Review Council (DSARC)/Development Concept Paper (DCP) Procedures for Major Defense Systems.

1. The DCP prepared for use at the time of the Program Initiation Decision (Milestone I) for a major Defense System will identify the critical questions and areas of risk to be resolved by test and evaluation. It will also provide a summary statement of test objectives, schedules, and milestones. The DSARC in its review will determine the adequacy of the statement of questions and issues and of test objectives and schedules.

2. When the DoD Component proposes to initiate Full-Scale Development the revised DCP will give the results of T&E accomplished to that date, an updated statement of critical questions and areas of risk still needing test to resolve, and a detailed statement of test plans and milestones. The DSARC will assess and comment to the Secretary of Defense as to the adequacy of T&E progress and of planned T&E to occur prior to the first major production decision.

3. The DSARC in its review prior to the first major production decision will assess and comment to the Secretary of Defense as to the adequacy of test results to support a decision to proceed with major production and the adequacy of plans and schedules for any remaining testing.

4. In case of DCP revisions and DSARC reviews subsequent to the first major production decision, an updated assessment of test

results and plans and schedules for additional test and evaluation will be presented.

V. WAIVERS

A. In the case of major programs, any waiver of the accomplishment of the T&E as outlined in the approved DCP will be granted only by the Secretary of Defense.

B. For other than major programs, the DoD Components will designate the minimum threshold for definition of less than major programs. For such programs the waiver of the required T&E will:

1. Within the Military Departments, be granted only by the Secretary, the Under Secretary, or such Assistant Secretary as the Secretary may designate.

2. Within the Department of Defense Agencies, be granted only by the Director.

VI. EXCLUSIONS

Test and evaluation of nuclear weapons subsystems which are governed by other joint DoD/AEC agreements are excluded from the foregoing provisions of this directive.

VII. RESPONSIBILITIES OF THE DEPUTY DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING, TEST AND EVALUATION (DD(T&E))

The DD(T&E) has across-the-board responsibility for OSD in test and evaluation matters. This responsibility includes:

A. Reviewing test and evaluation policy and procedures applicable to the Department of Defense as a whole and recommending changes he believes appropriate directly to the Secretary of Defense.

B. Monitoring closely the test and evaluation planned and conducted by the DoD Components for major acquisition programs and for such other programs as he believes necessary.

C. Assisting in the preparation of, and/or reviewing, the Test and Evaluation Sections of DCPs and Program Memoranda (PMs).

D. For major programs, reporting to the DSARC and the Worldwide Military Command and Control System Council as appropriate, and directly to the Secretary of Defense for such programs, at each major milestone decision point his assessment as to the adequacy of the identified critical issues and questions to be resolved by test and evaluation, test plans and schedules, and the adequacy of the accomplished T&E to justify the action recommended for that milestone decision.

E. Monitoring closely such joint testing as is accomplished by the DoD Components in connection with their planned acquisition of specific systems. In addition, initiating and coordinating the accomplishment of such additional joint testing as is necessary, with specific delegation to an appropriate Component (or Components) of all practical aspects of the joint test.

F. Coordinating and reviewing the test and evaluation of foreign systems for possible DoD use.

G. Fulfilling OSD responsibilities for the National and major Service test facilities.

H. Monitoring, only to the extent required to determine the applicability of results to weapon system acquisition or modification, that test and evaluation:

1. Directed by the Joint Chiefs of Staff which relates to the Single Integrated Operational Plan (SIOP) operational factors.

2. Conducted primarily for development or investigation of organizational or doctrinal concepts.

To accomplish these duties, statements of critical issues for DCPs/PMs, test plans for their resolution, and test results will be made available to DD(T&E) at his request as early as developed.

VIII. <u>REPORTING REQUIREMENTS</u>

The reporting requirements prescribed herein are exempt from formal approval and control in accordance with III.D.3., of DoD Directive 5000.19.

IX. <u>EFFECTIVE DATE AND IMPLEMENTATION</u>

This Directive is effective immediately. Each DoD Component which has authority and responsibilities under reference (a) will implement this Directive within 60 days and will forward three copies of each implementing document to the Director of Defense Research and Engineering.

Kenneth Rush
Deputy Secretary of Defense

AN ANALYSIS OF

INDEPENDENT RESEARCH AND DEVELOPMENT/BID AND PROPOSAL

(IR&D/B&P)

March 1975

The IR&D Task Force

of

The Defense Science Board

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

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

30 April 1975

MEMORANDUM FOR SECRETARY OF DEFENSE

THROUGH: DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

The Defense Science Board's Task Force on Independent Research and Development (IR&D) has completed its study of IR&D considering the rationale for supporting IR&D, the administration of the IR&D Program by the Department of Defense and the alternatives for the contractor recovery of IR&D costs. The final report on the study is hereby submitted. The conclusions and recommendations of the Task Force are summarized in the first few pages of the report.

Solomon J. Buchsbaum
Chairman
Defense Science Board

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

18 April 1975

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Report of the Task Force on Independent R&D

Submitted herewith is the report of the Defense Science Board Task Force on Independent Research & Development. The Task Force supports the national policy of dependency primarily upon industrial suppliers for goods and services and emphasizes strongly that the exercise of an independent research and development effort by the potential contractors is a necessary condition for promoting competition and making progress.

The Task Force believes that much of the confusion surrounding the Defense Department funding of Independent Research and Development (IR&D) and Bid and Proposal (B&P) expense is associated with a misunderstanding of their roles. The Task Force has devoted considerable attention to this problem and has attempted to point out that the support of contractors' Competitive Technical Effort (CTE), which collectively describes IR&D and B&P, is necessary to achieve maximum returns to the Government.

We find no significant deficiencies in the present system but do believe that simplifications and improvements can be made such that the burden on the Department and the contractor can be reduced while still obtaining the benefits of technical information exchange, planning and competition.

The Task Force has discussed its conclusions and recommendations with the IR&D Policy Council.

Gerald F. Tape

Gerald F. Tape
Chairman, Task Force on
Independent R&D

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## EXECUTIVE SUMMARY

The Task Force concurs in the national policy that requires the Department of Defense to rely primarily on competition to select sources for developing and producing its military hardware and for providing it with needed services. The Task Force believes that the DoD's own best interests are served in this way. It also believes that DoD reimbursement of independent Competitive Technical Effort (CTE) - the combination of Independent Research and Development (IR&D) and Bid and Proposal (B&P) - is necessarily implied by such a policy. Finally, it believes that the CTE allowance is basically a method of compensation for past costs incurred by the contractor in preparing himself to compete technically and pricewise for the contracts against which the allowances are charged. Prior approval of the content and relevancy of CTE activities is, therefore, not really appropriate.

Specifically, since much of the benefit of competition flows to the government, the Task Force recommends that:

- the DoD reimburse, through overhead, defense contractors for CTE in the amount considered necessary to maintain a truly competitive environment among DoD's industrial sources of supply;

- the amount of CTE authorized be determined to the greatest extent possible automatically on the basis of commercial market place experience or negotiated on the basis of simple formula and guidelines changeable by DoD periodically as conditions dictate;

- the DoD IR&D Policy Council provide guidance as to the level of CTE reimbursement by setting CTE policy and guidelines, and reviewing CTE goals and results at regular intervals;

- the DoD not attempt to manage, direct, or require prior approval of the substance of CTE programs; however, continue technical exchanges for the benefit of contractor and DoD;

- DoD reduce the tendency to be more restrictive than the agency-wide intent of the law in defining relevancy, by issuing instructions that assure that relevancy tests are not limited by the narrow interests of reviewing specialists. In any consideration of future changes, DoD should support the view that it is in the Government's greater interest that there be no tests for relevancy applied to CTE, or, at a minimum, that such tests be for Government-wide benefits, not simply for individual agency benefits; and

- the DoD promote the use of inter-agency coordinated CTE policy and procedures to the extent other agencies depend on competitive sources of supply in the way DoD does, but not support a central agency for CTE administration.

In utilizing the term CTE in this report to describe collectively IR&D and B&P, the Task Force does not intend that the present systems be rewritten to replace the terms IR&D and B&P.

As a final note, while the Task Force believes that the DoD should support a strong CTE among its contractors, it recognizes that CTE is only one aspect, though an important one, of the large and complicated question of how best to establish and maintain a competitive industry to serve DoD needs. It therefore warns against attempting to solve the whole problem through control of CTE, an attempt that is not only unlikely to succeed, but which may lessen the contribution CTE itself makes.

A more detailed listing of the Task Force's Conclusions and Recommendations is provided on the next two pages.

## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

I. The major benefits from IR&D are derived principally from the "I"; namely, the independence of choice and execution by the contractor.

II. CTE (IR&D/B&P) is a legitimate cost of doing business and is logically an overhead expense.

III. The treatment of CTE expense and the test for reasonableness should be closely coupled to commercial practice and as free from technical audit judgment as possible.

### Recommendations

1. Competitive Technical Effort (CTE), independently conducted by a contractor, must be accepted as an essential component in the maintenance of a competitive industrial base responsive to DoD needs.

2. CTE must be considered in conjunction with direct contract/grant R&D and in-house R&D; each has a role to play in maintaining the Nation's technological base and capability.

3. Treatment of CTE expense, including burden but not G&A, as an overhead cost element should be continued.

4. The DoD should employ to the greatest extent possible competitive market place controls over contractor IR&D/B&P (CTE) and less judgmental pre and post audit-type controls. In doing so, subjective tests for reasonableness would be replaced where applicable by objective criteria as illustrated by the CWAS concept.

5. The DoD IR&D Policy Council should exert greater control at the policy level, reviewing CTE trends and needs, establing guidance for reimbursement and implementation, etc. This efford should concentrate on minimizing the number of negotiated agreements, in providing crisp guidance and

procedures to shorten the negotiating periods of advance agreements and in expediting implementation at the field level. Negotiators should be encouraged to refer unusual situations to the Service Policy Councils for specific guidance.

IV. <u>Government controls on CTE in the absence of direct and continuing market pressures on contractor costs should seek to achieve an optimum balance between protecting the Government's interest and encouraging the greatest freedom in the exercise of the CTE resource.</u>

6. Relevancy requirements ultimately should be eliminated in their entirety or, as a minimum, the narrow agency relevancy requirement be broadened to one of government-wide relevancy. In the meantime, DoD should reduce the internal tendency to be more restrictive than the agency-wide intent of the law.

7. Effective technical exchanges between the contractor and appropriate DoD personnel are important and should continue to be encouraged, but not for the purpose of prejudging IR&D programs.

<u>All agencies of the government should support CTE to the extent that the contractors involved are a part of a pool of competitive suppliers.</u>

8. Where other government agencies rely on competitive sources in a manner similar to DoD, DoD should encourage CTE policies and procedures that recognize CTE as a necessary business expense.

# An Analysis of Independent Research and Development/Bid and Proposal

## INTRODUCTION

The issue of reimbursement of contractors' independent research and development and bid and proposal costs (IR&D and B&P) has had a long history within the DoD and the government generally. The debate has usually centered around amount, specific relationship to individual contracts, control and financing. An added consideration for the government as a whole and a concern expressed by many contractors has been the lack of uniformity in treatment from agency to agency.

The Defense Science Board (DSB) Task Force on IR&D has reviewed the extensive work done by others both inside and outside of the government in the examination of IR&D policies and procedures. Discussions were held with members of an industry Tri-Association study group; with the IR&D Directors from several defense industry firms; with senior representatives of government agencies, such as DoD, AEC, NASA, SBA, GAO: and finally with representatives of small contractors, some working exclusively in the commercial market place, some working almost exclusively for the government, and others with mixed product lines.

The Task Force was asked not to start de novo but to reassess the fundamentals concerning IR&D/B&P with specific emphasis on:

1. the various objectives and uses of IR&D/B&P from the viewpoints of both the government and industry, and

2. alternate means for satisfying the various objectives, including analysis and evaluation of methods to be used.

The full charter of the Task Force is included in Appendix 1; the membership of the Task Force is given in Appendix 2.

To avoid misunderstandings, the definitions used by the Task Force are those developed by DOD and are stated in Appendix 3. The major points of the present DoD policy on IR&D/B&P and the general features of its implementation are given in Appendix 4.

## RELATED STUDIES

At the request of the Chairmen of two Senate Subcommittees and a member of the House, the General Accounting Office (GAO) has undertaken a study of IR&D/B&P and has submitted a number of questions to the DoD. The basis for the GAO review appears to be a questioning by some Members of Congress as to whether there should be increased government control over that part of a contractor's IR&D/B&P that is reimbursed by the government, whether there should be more emphasis on direct R&D contracting versus IR&D, and whether there should be a budgetary ceiling on the total IR&D supported by DoD. The GAO study is still in progress; however, the GAO has issued a partial report of its investigation (dated 16 Aug 1974).

On the industry side, the Ad Hoc Committee on IR&D/B&P of the Tri-Association (Electronic Industries Association, Aerospace Industries Association and National Security Industrial Association) has completed a study of the subject and has presented a statement of principles and recommendations in a Position Paper dated 22 March 1974. (See Appendix 5 for a listing of specific recommendations.) The following recommendations are pertinent to this discussion:

1. The requirement for potential military relevancy should be eliminated.

2. The requirement for establishing ceilings on IR&D/B&P costs should be eliminated in the interest of encouraging competition and maintaining a strong industrial capability.

3. IR&D/B&P costs are indirect costs, part of overhead, and should not become line items in agency budgets.

4. IR&D/B&P are indirect business expenses and should be fully reimbursed. The government should pay for such costs on the same basis as all other customers.

The Commission on Government Procurement included recommendations on IR&D in its December 1972 report; the majority view, set forth under recommendation B-10, sought to:

1. recognize in cost allowability principles that IR&D and B&P expenditures are in the Nation's best interests to promote competition, to advance technology, and to foster economic growth;

2. establish a policy recognizing IR&D and B&P efforts as necessary costs of doing business and provide for a) uniform Government-wide treatment, b) acceptance of company practice when over 50% of sales are accounted for by firm fixed price Government contracts and commercial products and services, and c) application of relevancy to a potential agency function or operation when contractor cost centers have more than 50% cost-type contracts.

There were dissenting views by some members of the Commission. These included, inter alia, a more encompassing requirement for relevancy, greater access to contractor records in order to determine allowability, and annual agency reporting to the Congress on criteria and magnitude of allowances. An additional dissent noted that other mechanisms to achieve the benefits of IR&D had not been sufficiently explored and further study was necessary. The recommendations of the Commission on Government Procurement are under review by the Executive Branch; a policy position has not been established.

Other principal documents reviewed by the Task Force included "A Review of IR&D" dated February 1974, prepared by a DoD Working Group on the Nature, Objectives and Effects of the Independent Research and Development Program, and a staff report to the Commission on Government Procurement entitled "Independent Research and Development Special Project No. 1" by James E. Carpenter. A bibliography of the more significant documents considered by the Task Force is given in Appendix 6.

No attempt has been made to present individual points of view nor to distill the essence of the various discussions or studies. The Task Force has, however, as a result of all of its discussions and deliberations, reached certain conclusions and offers recommendations which are later set forth.

## COSTS AND TRENDS

The costs associated with IR&D/B&P programs of major DoD contractors since 1964 are given in Appendix 7. The contractors included are estimated to account for more than 85% of all IR&D/B&P (and in earlier years OTE) expenditures recovered in DoD contracts. It must be noted that many changes have taken place that make trend comparisons difficult. For example: (1) A requirement for reporting burdened dollars was introduced (this did not take place at one time and the actual figures for a number of years are a mixture of burdened and unburdened dollars); (2) the base of contractors reported on changed from year to year (while a large number of companies are in the base through the entire time period, the remaining part of the data base varies considerably from year to year); (3) the DCAA current rules for companies to be reported is different in the last years than in the initial years; (4) OTE costs reported separately in earlier years have in later years been included for the most part in IR&D reporting.

From Appendix 7 it will be noted that for 1974, 90 major defense contractors incurred total costs of $1,694 million. Through advance agreements with the larger contractors and by application of a formula for others, the DoD considered as "acceptable", cost of $1,405 million. Since these contractors also have non-DoD contracts, the DoD portion, allocated on the basis of sales, was $808 million, about 57% of the total acceptable. It should be emphasized that under the present DoD policy, essentially all of these expenditures, $779 million out of the $808 million, were covered by advance agreements. The comparable figures for IR&D only were $445 million out of $457 million.

## IR&D/B&P - THE TASK FORCE APPRAISAL

### The Need for Independent Technical Effort in Contractors' Organizations

Every successful organization must have the ability to survive in the competitive market place. This applies to the U.S. Government in its continuing effort to maintain a world leadership role, to provide for the Nation's security, and to satisfy the needs of its citizens. The U.S. Government provides a framework within which elements of its society can operate but leaves much of the actual responsibility for meeting these needs to the private market place. The necessary continuing technical advances therefore, result principally from the individual initiative of those interested in and having a responsibility for education, research, development, production and provision of services. From long experience, we have found that the most innovative and productive ideas stem from grass roots initiatives by those individuals and organizations that recognize and understand what needs to be done and what can be done.

All organizations, and especially those whose continuing success is dependent upon more advanced technologies, must carry out research and development in order to remain aware of and to make advances in the state of the art, generate new products or new techniques to meet ever-changing needs, reduce costs, etc. In other words. they must remain competitive. This applies to universities in generating new knowledge and in training students, to Government laboratories in fulfilling their commitments to their respective agencies, and to industry in supplying products and services for both the public and private sectors.

R&D of the highest quality is necessary for the preservation of our National security since we must be prepared to cope with potential adversaries who continue to demonstrate their full commitment to advanced and ever-improving military systems. The question is how best to obtain the necessary R&D to satisfy U.S. needs. A part of the answer is that we must take advantage of all possibilities, ranging from that which is controlled and directed by the customer, i.e., the Government, to that which encourages the greatest possible independence and initiative by the supplier.

Virtually everyone the Task Force talked to, as well as the Task Force members themselves, believe that IR&D/B&P plays a role in meeting DoD needs that is at least highly important if not absolutely necessary. Yet it is clear from the history of IR&D and the voluminous documentation made available to the Task Force that IR&D has been almost continuously subject to serious challenge. The challenges have usually been about one or another aspect of the procedures for handling IR&D and how independent it should be rather than whether or not IR&D should exist. Since, however, there did not seem to be anything seriously wrong with existing procedures, the Task Force came to the conclusion that the real trouble may lie in the lack of a generally-agreed upon, or perhaps understood, rationale for IR&D for which a consistent set of procedures could be applied. It became clear that without agreement on why DoD supports IR&D and what it hopes to accomplish by so doing, the misunderstandings would remain.

The Task Force, therefore, discussed this problem at some length and has defined a rationale which it believes goes to the heart of the issue.

## A Rationale for IR&D/B&P

The two fundamental questions concerning Government support of IR&D/B&P are:

- Why should the Government reimburse expenditures for IR&D/B&P?

- If there are sound reasons for such reimbursement, what rules should be used to allocate the funds available for it among competing claimants?

The answers commonly given to the first question include objectives such as to increase knowledge, to improve technology, to explore and test innovative ideas and concepts, to retain key staff, etc. These are all worthy objectives and they contribute to the health of the defense community. Since they are generally stated in industry-benefiting terms, the question naturally arises: Since they are beneficial to industry, why shouldn't companies use their "own money" to pay for them rather than expecting the Government to do so? And, even if beneficial to industry, what makes them beneficial to the Government?

The answer commonly given to the second question generally takes the form of a statement that work of this sort is a necessary cost of a firm's doing business, and, therefore, should be paid for by any customer -- including the Government. While this is valid, under the present method for reimbursing IR&D/B&P expenditures confusion arises since the Government seems to be paying the costs of preparing for and acquiring future work as part of the expense of current, sometimes unrelated contracts. This raises questions such as: Why should the Government invest in a company's future work? And how can the Government be sure that the money invested is actually spent in work from which it can benefit?

<u>Why should the Government support IR&D/B&P?</u>

The Government has decided as a matter of National policy that the Department of Defense and other Government agencies should rely primarily on competition to select sources for developing and producing its military hardware and providing them with needed services. The Task Force believes that this policy is fundamentally sound. Competitive procurement, whether of a formal or informal nature, will in the long run be more efficient and economical, result in higher quality, and be more flexibility responsive to DoD's changing needs.

This policy has a price, however. The price includes assuring the continued existence of sufficient number of organizations qualified to meet DoD needs so that a truly competitive environment can exist. Furthermore, these organizations must be sufficiently staffed with qualified and knowledgeable people that they can do the jobs required. The cost of conducting the actual competitions must also be met. To the private organizations involved in the competitions, this cost is the expense of preparing quality proposals, with all the underlying technical and administrative activities that such proposals require. To the Government, the cost is that of informing industry of its needs, managing the competition, evaluating the proposals and selecting the performer. These costs are not small. They are, in fact, substantial; but they are considered to be more than justified by the savings accruing to the Government from effective competition as well as technology growth inherent from such competition.

Since the ultimate benefits of such competition accrue to the Government, it is the Government which must pay for the cost of them. Part of such cost is what is commonly called IR&D/B&P -- the technical activities of the competitive companies including research, development, design, demonstration, proposal writing, etc., i.e., all those activities required for them to engage in real competition. As a result, such activities might better be described as Competitive Technical Effort - CTE.

Thus, the answer to the first fundamental question -- why the Government should reimburse the costs of IR&D/B&P -- is that it must do so to help gain the benefits of competition, benefits which are the essence of a free enterprise system. It should be emphasized that if the Government is unwilling to pay in some fashion for the price of such competiton, then the competitive atmosphere will weaken as some organizations withdraw from the arena and others cease to make significant investments in the competition, thereby resulting in proposals that are inadequately supported or technically unimaginative. In either case, the DoD would be left in a position in which it would not have real choices, but would have to make its source selections on the basis of less appropriate criteria, such as, for example, whose turn is next.

DoD like the AEC and NASA does, of course, satisfy some of its needs through the use of organizations which are essentially "chosen instruments" in various areas, selected to compete for specific programs and paid to do so as a part of their contractual relationships with the Government. These include in-house laboratories, GOCO (Government-owned contractor-operated) organizations and FCRC's (federal contract research centers). But, while important to DoD and other Government agencies to be able to provide this type of tailored competition for special needs, this approach is not the solution to their obtaining the vast bulk of the goods and services they need annually.

How should the Government pay for Competitive Technical Effort?

A private contractor must have made an investment in CTE for him to have obtained a competitive contract. The Government should, therefore, permit the contractor to recover prior CTE costs as a part of each such contract. The Government should recognize that CTE costs are company-initiated costs, made under company control for the purpose of being able to satisfy Government needs in a competitive manner. The Government should also recognize that it is really compensating a contractor for his investment only if he has been successful in obtaining a contract. In fact, it should be clear that the Government will reimburse only successful contractors and not those whose prior CTE was not good enough to satisfy some Government need.

Successful competitors will wish to use CTE monies recovered on contracts in a variety of ways, all being investments in the future, that is, directed at increasing the contractor's ability to obtain new contracts. The choices are up to them. It is also up to them to decide what contracts -- and, in fact, what customers -- they wish to go after, and to decide how to allocate the money in their various CTE activities. They can invest more if they are hopeful that this will pay off; they can invest less if they are pessimistic. The essential point is that recovered CTE monies provide an opportunity to invest in ways determined by the company to enable it to engage effectively in valid competitions.

If a company is successful on the average in competitions, such investments will pay off; if a company is unsuccessful on the average, CTE investments will fail to pay off. "On the average" is stressed because, to stay in business, contractors must recover their CTE costs on unsuccessful as well as on successful bids. If, for example, the Government would like three bidders on the average, then the average contractor will achieve one success out of three tries and must recover CTE costs expended on the two failures as well as CTE costs related to his one success.

With the exceptions noted in the following discussion, the present DoD procedures for reimbursing CTE costs are believed to recognize the factors discussed in the previous paragraphs.

Possible Procedures

Having established that CTE is the price that the Government must pay to maintain competitive sources of supply and that the payments should be considered as reimbursements for past expenditures, there remains the problem of how to size, allocate, and control Government CTE reimbursements.

The simplest and most ideal solution to this problem is also the one most consistent with the stated philosophy - successful contractors would be allowed to recover CTE costs through charges to overhead up to a maximum determined by a simple formula.

The formula would be determined at the highest level in DoD, probably by the IR&D Policy Council, and would be based on a considered, periodic judgment of the needed level of competitive activity. Allocation among contractors would be based primarily on this formula but deviations therefrom deemed desirable by contract negotiators would be possible as a result of review by appropriate authority. Such deviations might recognize magnitude of total contractor effort, unusual year to year fluctuations or other special circumstances.

Since reimbursements would be for past independent technical activities (which were, by definition, successful or the contractor would have no contracts against which to recover them), there could be little question of relevancy, or content, or quality. Thus, no IR&D planning documents would be required and no technical evaluations of such plans would be called for. New CTE activities would be truly independent and contractors would recover their costs only if they ultimately bore fruit in new contracts. Normal pressures on contractors to find out what the DoD wants and to tell DoD of their capabilities would be depended on to force the needed information interchange.

The question arises: Suppose the contractor, for whatever reasons, does not apply his new CTE in a fashion that leads to effective competition for new Government work? There are two answers to this question. The first is that it is really his money; and if he wastes it, it is his mistake. The second is that, if he wastes it, he will fail to win future contracts, his contract level will fall and the DoD reimbursement for CTE will likewise fall. In the long run, the system would thus be self-correcting.

The Task Force does not, however, recommend that DoD embrace this ideal CTE procedure completely, despite its attractive consistency and simplicity. The Task Force recognizes the special nature of the DoD's relationship with its major contractors and hence that IR&D/B&P reimbursements in a given case do not always result as fully and directly from competitive technical effort as ideally envisioned. It also recognizes the Government's duty to oversee the expenditure of taxpayer money, even if such oversight reduces effectiveness and increases costs to some extent; and it is aware of the existence of a considerable body of pertinent law, regulations and precedent. Most importantly, the Task Force recognizes that there are varying degrees of competition involved in DoD procurements. Competition covers a broad spectrum from formal price competitions for commercial shelf-items at one extreme, through informal competitions for design ideas and capabilities, to chosen instruments of long duration at the other extreme. These variations in competition and the differing degrees of cost control consciousness that these variations may invoke, need to be recognized and dealt with, even at the expense of some increase in the complexity of IR&D/B&P procedures.

Finally, the Task Force recognizes that DoD has a need to keep close track of the CTE process, in order both to assure itself that CTE is playing its proper role in the larger matter of maintaining DoD's competitive sources of supply and to provide informed judgment to future CTE policy decisions.

The Task Force had neither the time nor sufficient detailed knowledge to conduct an adequate study of the procedural aspects of the problem. It, therefore, presents the suggested procedure more as an illustration of what it believes is needed than as a definite set of recommendations. The Task Force suggests a simplified version of the existing DoD procedure along the following lines:

1. The contractor-determined CTE overhead charge should be accepted where competition and continuing cost consciousness can be clearly demonstrated, i.e., where cost centers are dominated by competitive, firm, fixed-price contracts either Government or non-Government.

The goal should be to remove as many contractors from more detailed consideration as is reasonable based on an adequate competition/cost conscious environment. The criterion ought therefore to be easily understood and readily accepted as opposed to covering all possible special circumstances.

2. Where this situation does not exist, contractors (cost centers) should be divided into two classes:

a. Small (DoD reimbursed CTE less than $2.0 million) - use a formula set by the IR&D Policy Council. Exceptions either up or down would be allowed with justification and appropriate approval.

b. Large (DoD reimbursed CTE greater than $2.0 million) - negotiate a dollar ceiling, consistent with standards developed and promulgated by the IR&D Policy Council.

3. Technical reviews should be kept to a reasonable level. Company brochures should be kept simple and used primarily for conveying information; and overhead costs associated with present reviews, which are probably too high for both government and contractors, should be reduced. The Task Force also believes that visits to contractors should be primarily to review past and on-going activities rather than future plans and that visiting groups should be made up primarily of those government people who are working in the fields to be covered and who want to go for their own information. Finally, the Task Force believes that reliable evaluations of quality are unlikely to result from the limited time that government scientists can apply to the review of brochures or to quick visits and therefore questions the desirability of computing an evaluation score to be used in negotiating the CTE level. The self-correcting nature of the overall system, as mentioned above, seems to be the best guarantee of quality.

4. The Task Force understands that, however undesirable it may be, the law requires a test for "a potential relationship to a military function or operation" and that it is therefore not within the discretion of the DoD to omit such a test. Further, the Task Force notes that Service procurement managers are all understandably tempted to lock in their suppliers to their own interests when they can. The Task Force believes that the DoD should resist this temptation and take a broad view of the Government interest. As a result, the DoD definition of relevancy should be clearly

stated -- and the instructions, procedures and forms used designed -- to assure that the test is at least DoD-wide and not limited to the parochial interests of reviewing specialists. Furthermore, narrow interpretations should be avoided by contract officers.

5. The IR&D Policy Council should play a strong role in determining CTE policy, establishing the relationship of IR&D/B&P to the defense environment, setting formulas, and in reviewing overall results. Such a role is needed to assure proper DoD awareness and control of this large and important Government investment.

Alternate Recovery Methods

The Task Force was asked to consider alternate methods for reimbursing or financing CTE (IR&D/B&P). It concluded that the present procedure of reimbursement as an item of indirect expense should be continued. *Alternate methods considered included funding as a direct cost, from profits, and through tax credits. Comments on these rejected alternatives follow:

- Direct cost reimbursement places CTE in the same category as direct research contracting and subjects it to all of the same judgments and controls at the many Government levels involved. In short, all of the advantages of independence in R&D are lost without any compensating benefits.

- Financing from profits would provide the independence sought for CTE, namely, complete company control. One difficulty is that present fee structures would have to be revised significantly upwards to allow for the necessary CTE funding (perhaps 3-5% after taxes). An upward revision of fee structure does not seem likely. A second difficulty is that the Government and Industry under the present arrangement conduct a considerable amount of technical interchange. This might be diluted under complete company control and result in limitations on the dissemination of technology.

- From time to time there have been proposals to permit IR&D-type costs to be recovered in whole or part as tax credits. IR&D cost recovery is only part

* Toward the end of its work, the Task Force was made aware of the GAO's list of 14 possible alternatives. In the opinion of the Task Force, these are not independent alternatives but variations within the categories that had already been considered.

of a larger program of tax credit incentive problems which must be solved. Since the tax credit route would probably not eliminate some test of reasonableness which is also necessary under the overhead allocation procedure, the latter is preferable.

## CONCLUSIONS AND RECOMMENDATIONS

### General

The Task Force concurs in the policy that requires the Department of Defense to rely primarily on competition to select sources for developing and producing its military hardware and for providing it with needed services. Therefore, the conclusions and recommendations which follow address the question of how best to maintain a highly competitive industry, especially in fields of advanced technology that are of greater importance to the military than to the civilian market.

The Task Force believes that the Government should encourage a strong contractor Competitive Technical Effort - CTE (IR&D/B&P). At the same time, it recognizes that CTE is but one aspect, albeit an important one, of the large and complicated question of establishing and maintaining a competitive industry to serve DoD needs. The Task Force warns against attempting to solve the whole problem through control of CTE, an attempt that is not only unlikely to succeed but may lessen the contribution CTE itself may make.

The present system of implementation by the DoD is generally satisfactory. The following recommendations are made in part to emphasize various important features of CTE and in part to propose improvements such as administrative simplification, greater reliance on market place type controls, greater decision authority remaining with performers, etc.

Conclusion I. The major benefits from IR&D are derived principally from the "I", namely, the independence of choice and execution by the contractor.

Direct contracting (including grants) for research and development is most useful when end objectives or fields of research are clearly specified. Government specialists then play an important role in selection and direction. The selection process is complex and the response time, which must include budgetary consideration and planning, is long.

Direct contracting will and should remain the principal method for controlling the major allocation of R&D resources. With the wide variety of projects to be accomplished, different performers can be employed as appropriate, e.g., academic, not-for-profit, Government in-house, and industrial institutions.

The benefits from Independent R&D stem principally from the contractor's flexibility in decision making and execution of the work. Those with the deepest technical involvement are encouraged to innovate. Research and development decisions as to what, how, who and when are made where the work is done. Immediate judgments by peers permit more rapid and imaginative responses.

Additionally, the present procurement process depends heavily on guaranteed success, that is, previous extensive R&D, testing, evaluation, etc. Exploratory and conceptual research, component development and early testing through IR&D provide a better base from which DoD decisions for follow-on R&D or fabrication contract effort can be made.

All in all, IR&D is a major component of the contractor's Competitive Technical Effort. It provides him with both the expertise and knowledge with which to respond promptly and responsively as well as to propose new innovative concepts.

Recommendation 1.

Competitive Technical Effort (CTE), independently conducted by a contractor, must be accepted as an essential component in the maintenance of a competitive industrial base response to DoD needs.

Recommendation 2.

CTE must be considered in conjunction with direct contract/grant R&D and in-house R&D; each has a role to play in maintaining the Nation's technological base and capability.

Conclusion II. CTE (IR&D/B&P) is a legitimate cost of doing business and is logically an overhead expense.

All organizations, especially those engaged in advanced technology programs, must support strong programs of CTE. It is a cost of remaining competitive and must be recovered either as a reimbursable cost or, if not allowable, from profits.

Recovery from profit would certainly provide the independence sought for CTE, namely, complete company control. The difficulty is that the present DoD fee structure would have to be revised upwards to allow for the necessary CTE funding (perhaps 3-5% after taxes) if gross profits from Government work were not to drop below present levels; such upward revision of fee structure does not seem likely. Yet to remain in business, a company must be profitable, and if it finds doing business with DoD is not profitable it will seek other customers where it can remain profitable.

Treating CTE as a direct cost places it in the same category as direct research contracting and subjects it to all of the same Governmental judgments and controls while losing all of the advantages of independence.

In the final analysis, CTE is an incurred cost having a bearing on the company's (or cost center's) total effort especially as that effort influences its future business. Since such work is not necessarily associated directly with an on-going product line, it should be expensed as an overhead cost and distributed in accordance with accepted accounting principles.

Recommendation 3.

Treatment of CTE expense, including burden but not G&A, as an overhead cost element should be continued.

Conclusion III. The treatment of CTE expense and the test for reasonableness should be closely coupled to commercial practice and as free from technical audit judgment as possible.

Given that CTE is a necessary business expense, the question then centers on how much CTE is necessary. When buying a commercial product at a catalogue or shelf price, the amount of CTE expense included is not in question since it is included in the total price arrived at through market place forces. For a firm fixed price contract based on competition, the element of CTE expense is also in the firm fixed price and is therefore subject to cost control. The question of "how much" arises when the contract negotiated is sole source or cost-type and the Government negotiator is looking for a test of reasonableness.

Since the Task Force recommends that CTE be treated as an overhead expense, the problem is then one of negotiating an acceptable overhead allowance of which CTE is but one component. The present DoD-ASPR system recognizes this and also that CTE deserves special attention, especially for the larger contractors. Thus for a CTE annual cost of less than $2.0 million per contractor, general overhead negotiating principles are followed with formula guidance on CTE for the negotiator. For contractors with larger CTE expense, dollar limits based on technical quality and relevancy tests are negotiated in advance.

Experience to date indicates that most high-technology defense contractors find it desirable if not necessary to spend more for CTE than the Government is prepared to reimburse. While this factor must be taken into account in the evaluation of reasonableness, it would be unrealistic to expect full reimbursement of CTE costs in those instances where there are few, if any, market controls on those costs.

The Task Force recognizes that many advantages are to be gained through simplification of the tests for reasonableness. This could be automatically accomplished by making as much procurement as possible competitive firm fixed price. Next, where strong and continuing competitive cost pressures exist on a company's allocation of its own resources, the company's own decisions can be utilized for negotiated Government contracts as well. In short, every effort should be made to accept the pressures of competition and continuing cost consciousness as automatic tests for reasonableness where they exist.

In an earlier section of this report, entitled "Possible Procedures", the Task Force has offered a suggested procedure which in its opinion would provide for simplification, greater independence for some contractors, controls for DoD in the most sensitive areas, and exchange of technical information.

Recommendation 4.

The DoD should employ to the greatest extent possible competitive market place controls over contractor IR&D/B&P (CTE) and less judgmental pre and post audit-type controls. In doing so, subjective tests for reasonableness would be replaced where applicable by objective criteria, as illustrated by the CWAS concept.

Recommendation 5.

The DoD IR&D Policy Council should exert greater control at the policy level, reviewing CTE trends and needs, establishing guidance for reimbursement and implementation, etc. This effort should concentrate on minimizing the number of negotiated agreements, in providing crisp guidance and procedures to shorten the negotiating periods for advance agreements and in expediting implementation at the field level. Negotiators should be encouraged to refer unusual situations to the Service Policy Councils for specific guidance.

Conclusions IV. Government controls on CTE in the absence of direct and continuing market pressures on contractor costs should seek to achieve an optimum balance between protecting the Government's interest and encouraging the greatest freedom in the exercise of the CTE resource.

The principal Government controls in effect today are on those contractors whose CTE expense is in excess of $2.0 million. The requirement for an advance agreement based on technical quality, potential military relationship and reasonableness consumes considerable effort on the part of both contractor and Government and does impact on the contractor's independence in pursuing his R&D program. On the other hand, some exchange of technical information at the planning stage and at appropriate achievement stages is beneficial to both parties.

The Task Force finds that benefits from the technical reviews accrue to the Government through exchange of information and in the early disclosure of new directions and results. Similarly, the company benefits from guidance on priorities, duplications and evaluations. The Task Force believes, however, that industry's application of

CTE is best influenced by DoD through DoD's making known its future needs and intentions and not by judging in advance what CTE should be done to satisfy these needs. Therefore, current procedures may entail greater than necessary effort. More attention should be paid to the technical interests of those who participate. Review teams should be composed of those who will really contribute and benefit from such exchanges.

IR&D, almost by definition, should not be subject to a relevancy test. If, however, relevancy tests continue to be required, the Task Force fails to see why single agency relevancy should be applied, when the Government as a whole should benefit if possible from IR&D conducted by all Government contractors. Therefore, tests for relevancy, if necessary, should be general tests made by those who have a broad appreciation of relationships rather than by those seeking contributions to narrowly defined objectives.

Recommendation 6.

Relevancy requirements ultimately should be eliminated in their entirety or, as a minimum, the narrow agency relevancy requirement be broadened to one of Government-wide relevancy. In the meantime, DoD should reduce the internal tendency to be more restrictive than the agency-wide intent of the law.

Recommendation 7.

Effective technical exchanges between the contractor and appropriate DoD personnel are important and should continue to be encouraged, but not for the purpose of prejudging IR&D programs.

Conclusion V: All agencies of the Government should support CTE to the extent that the contractors involved are a part of a pool of competitive suppliers.

The purpose of a contractor's CTE is to permit him to supply, and the Government to obtain, the best product possible in terms of performance and cost. Since such competition is of benefit to the Government, the policies and procedures applied should be as consistent Government-wide as is possible. It is recognized that for various reasons there may be valid agency to agency differences. Thus, while the Task Force believes that there should be uniformity in the treatment of CTE among agencies having similar objectives and relationships with their suppliers, it sees the necessity for a clear understanding of the role CTE plays in helping a particular agency to accomplish its objectives and to maintain its supplier relationships before such uniformity is mandated. In any case, creating a central agency to administer CTE will not help.

Recommendation 8.

Where other Government agencies rely on competitive sources in a manner similar to DoD, DoD should encourage CTE policies and procedures that recognize CTE as a necessary business expense.

Appendix 1

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

12 April 1974

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Charter of DSB TAsk Force on IR&D

The letter of 8 November 1973 requested assistance from the DSB in the study of IR&D. As a result of several activities that are under way both in DoD and industry, it now seems clear that the prime thrust of the DSB effort should be the identification and examination of alternative ways to accomplish the various IR&D/B&P objectives, both government and industry.

Several studies currently under way, namely the GAO study and the Tri-Association Industry study, are primarily concerned with improved administration of the current DoD approach to IR&D/B&P allowance. There are many who believe that the current statutes and regulations concerning IR&D/B&P are so constrictive that a fundamental change in the policy may be necessary to preserve the independence and the innovation of the effort. Some hold the view that the single approach to the allowance of IR&D/B&P has never completely satisfied the sometimes conflicting objectives both of government and industry.

I am, therefore, requesting that the DSB Task Force effort be aimed primarily at a reassessment of the fundamentals concerning IR&D/B&P. It should address but not necessarily limit its work to the following tasks.

1. Identify the various objectives and uses of IR&D/B&P both from the government and from the industry viewpoints and assess the criticality of each objective and use. Included would be objectives, such as

- increasing the base of fundamental knowledge;
- advancing the technology of current product areas;
- advancing the technology of future product areas;
- retaining key technical and scientific talent;

- identifying, exploring and developing innovative components/subsystems/systems;

- initiating innovative and responsive proposals.

2. Identify alternative means for satisfying each objective as developed under task 1. These could include the usual techniques of overhead allowance and profit allowance but could also consider other means such as contracts, grants, competitively funded continuing concept studies, etc.

3. Set forth and assess the pros and cons of various alternatives and recommend possible modus operandi for achieving the most important objectives as concluded under the task 1 assessment.

The Task Force should seek inputs from a broad spectrum of government and industry being particularly careful to recognize the possible differences in objectives between government and industry and between companies of different size and product.

The Task Force should target its efforts for completion and presentation to the DDRE by 1 September 1974.

Robert N. Parker
Principal Deputy

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## DEFINITIONS

To avoid misunderstanding, the definitions used by the Task Force are those developed by DoD as follows:

### Independent Research & Development (IR&D)

A contractor's independent research and development effort (IR&D) is that technical effort which is not sponsored by, or required in performance of, a contract or grant and which consists of projects falling within the following three areas: (i) basic and applied research, (ii) development, and (iii) systems and other concept formulation studies. IR&D effort shall not include technical effort expended in the development and preparation of technical data specifically to support the submission of a bid or proposal. (ASPR 15-205.35).

### Bid & Proposal (B&P) Expense

Bid and proposal (B&P) costs are the costs incurred in preparing, submitting, and supporting bids and proposals (whether or not solicited) on potential government or non-government contracts which fall within the following:

(A) Administrative costs including the cost of the nontechnical effort for the physical preparation of the technical proposal documents and also the cost of the technical and nontechnical effort for the preparation and publication of the cost data and other administrative data necessary to support the contractor's bids and proposals, and

(B) Technical costs incurred to specifically support a contractor's bid or proposal, including the costs of system and concept formulation studies and the development of engineering and production engineering data. (ASPR 15-205.3).

### Relevancy

The requirement that IR&D work for which payment is received through overhead recovery on DoD contracts must have a potential relationship to a military function or operation. (Public Law 91-441, Section 203).

## MAJOR DOD IR&D POLICY AND IMPLEMENTATION FEATURES

### POLICY

1. Use individually negotiated advance agreements for the control and reimbursement of these costs for large defense contractors (approx. 100). Such agreements, after a formalized detailed technical review of the proposed IR&D program, will establish a separate dollar ceiling for the DoD's reimbursement of each of these costs, but allowing the contractor to combine the individual amounts into a single pool if he chooses; and requiring the contractor to burden these costs as he would for a contract, except that G&A would not be added. The requirements to negotiate a timely advance agreement will be enforced by automatically establishing a low threshold for recovery of these costs where no advance agreement exists.

2. Use the DoD developed formula for control and determination of reasonableness of these costs for the remaining large number of smaller companies who recover IR&D or B&P. This will provide a workable, uniform system that can be uniformally applied and easily adjusted as needed.

3. That technical review and evaluation of contractors' IR&D programs, as currently established under DoD Instruction 5100.66 be strengthened and that detailed review and evaluation procedures be established and made uniform throughout the DoD. The system will require both the review of a company's individual IR&D projects as submitted at the time of the advance agreement and will be supplemented by periodic technical reviews of the contractor's ongoing IR&D programs at his facility. In addition, a data bank will be established to provide a centralized body of IR&D project information. This information will be available to the DoD technical community at large.

4. That each of the Military Departments formally recognize the need to increase the support and resources needed to effectively perform the required IR&D technical reviews and evaluations by establishing a specific line item in the Management and Support Category of their RDT&E Program to support this technical review and evaluation effort.

5. That the Department of Defense continue its present policy of not acquiring rights to technical data and patents arising from industries' IR&D programs.

GENERAL IMPLEMENTATION FEATURES

1. For major contracts involving IR&D/B&P annual expense of over $2 million, advance agreements are negotiated. These agreements are based on technical quality, relevancy to DoD needs, and reasonableness. Costs include cost center burden but no general and administrative (G&A) expense since the allowed IR&D/B&P is finally treated as a G&A cost.

2. For all other contracts no advance agreement is necessary, but in negotiating overhead allowances, a formula for control and determination of reasonableness is used. No test for relevancy is applied nor are technical reviews carried out.

3. Technical reviews encompass a review of the IR&D technical plan at the time of negotiation of the advance agreement and periodic on-site reviews of ongoing IR&D programs.

4. Acquisition of rights to technical data and patents arising from IR&D programs is not required.

# TRI-ASSOCIATION STUDY OF IR&D/B&P

## PRINCIPLES AND RECOMMENDATIONS

As the subject of IR&D and B&P is undoubtedly headed for continued debate in the Congress again this year, it is important that this study of the industry position on IR&D and B&P be clearly understood. A number of points have become evident during the course of this examination of the subject. Some of these points are more properly defined as statements of principles; others are more appropriately presented as specific recommendations.

Let us first consider those points which constitute a statement of principles on the industry position on IR&D and B&P:

1. The Congress and all Government agencies should understand and fully recognize in their actions the vital nature of IR&D and B&P in support of our national interests. Relative to programs of key national importance, these activities play a major role in advancing the technological capabilities of those industries most directly involved in support of the Government. Examination of the benefits of these activities suggests that a substantial part of many technological advances that have resulted in the US position of world leadership in defense and space have had their genesis in IR&D.

2. The right of industry to exercise management discretion on the content and amount of IR&D and B&P should not be abridged by arbitrary laws or regulations. It is essential that each company be able to evaluate the needs of the future in light of its own special capabilities and product interests. This is not only basic to the continued development of vigorous competition in a strong industrial base, but also provide the most prolific generation of new technology and concepts to address problems of major significance to the Nation. Rather than consideration of means to control and constrain the scope of IR&D and B&P efforts, the Government should be jealously guarding the "independent" aspect to avoid the loss of great ideas.

3. The Government should be motivated to encourage industry to increase IR&D and resulting B&P effort. In view of the need for increased effort for the US to stay in the lead in the competition between nations, and the major source of technological innovation represented by IR&D and B&P, it seems obvious that they should not be allowed to decrease. Yet in the past five years, the level of effort expended on IR&D and B&P has decreased. The increased dollar expenditures have not been sufficient to maintain real effort in terms of man-hours. This point should be understood, and preoccupation with misleading cost data, which has not been normalized to account for Government-directed changes to financial reporting method, including application of burden to IR&D and B&P, should be avoided. The international challenge is great; this is the time to increase IR&D and B&P in terms of real effort to help meet the challenge, not the time for further retrenchment.

4. The Government should not seek ownership free rights in industry patents or inventions resulting from IR&D. This issue has been raised within the Government on numerous occasions in the past, and is a further indication that the nature of IR&D and B&P is not understood. It should be recognized that these efforts are company initiated and company funded within the indirect costs of doing business. The Government acceptance of its share of these costs appropriately allocated to Government contracts is no different than any other customer's payment of these costs included in the purchase price of a company's products or services. As any other customer, the Government benefits from improved products or services resulting from inventions conceived during IR&D. Equity demands the company retain title to its own inventions and patents.

5. A common policy and practice of independence and allowability of IR&D and B&P which recognizes their true nature as essential business costs should be employed by all Government departments and agencies. The restrictive regulations currently issued should be appropriately modified.

6. Congress should recognize that IR&D and B&P costs are not "commodities to be purchased," but rather are normal "costs of doing business." As such, they are appropriately allocated to all products

and services, and are included in the purchase price. On Government contracts, industry is required to negotiate burden rates. In the process, all indirect costs are reviewed and judgments are made as to the reasonableness of these costs. Legislation which singles out IR&D and B&P costs for undue scrutiny at the Congressional level implies that these efforts are "commodities to be purchased or not" and jeopardize a company's ability to plan and manage its total business activities.

7. The basic difference between IR&D and B&P should be clearly recognized. IR&D efforts are primarily exploratory in nature, are directed toward the advancement of technology, are aimed at future needs, and are subject to continual evaluation to determine if adequate progress is being made or if a new or different approach is needed. By way of contrast, B&P efforts are directed toward a specific set of requirements, are aimed at present needs, and are primarily concerned with thoroughly explaining that the company has already developed its expertise and technological capability to a sufficient degree to assure success. A company's proposal must demonstrate a complete understanding of all technical problems, to the point of describing therein a substantially finished design of a viable version of the system to be furnished, and discussion of the merits of the chosen design versus possible alternatives. Associated technical efforts range from studies, computer modeling and design calculations to, in many cases, the construction of prototypes. Also involved in the B&P effort is the actual preparation of proposals, engaging in presentations and negotiations, and otherwise responding to the requirements of the procuring agency. This effort is often difficult and sometimes impossible to forecast since companies are responding to evolving Government statements of need. Clearly, IR&D and B&P efforts should not be lumped together and treated as the same kind of effort simply because the same or similar technical experts of a company are called on to support each of them. They are different in purpose and are performed for very different reasons. IR&D effort can be reasonably well planned while B&P effort is much more difficult to forecast since it must be responsive to customer requirements.

Having stated these principles, and recognizing that the present method for handling IR&D and B&P costs does not fully conform to these principles, there are several specific recommendations that seem appropriate:

1. The requirement for potential military relationship in Public Law 91-441 should be eliminated as unworkable. Defense-related technology does not exist in isolation, but is part of the main stream of knowledge generally described as the national technology base. Relevancy tests are fundamentally incompatible with the nature of IR&D and B&P and invite hindsight judgments. If such tests must be included in legislation, they should appear only in the broadest context and be expressed in terms of the totality of potential US Government needs.

2. The requirement for establishing ceilings on IR&D and B&P costs should be eliminated because it is in basic conflict with stated Government objectives to encourage competition and maintain a strong industrial capability.

3. Line items should not be established in any agency budgets for funding IR&D and B&P costs as though these efforts were commodities to be priced. These are indirect costs, part of industry overhead, and as such are appropriately included in product or contract estimates.

4. A new Government agency responsible for operational aspects of IR&D and B&P should not be established. Rather all Government agencies should follow a common policy and practice for IR&D and B&P which recognizes their true nature.

5. Congress, in the national interest, should specifically express positive support for IR&D and B&P and correct the current motivation to continually reduce this effort.

6. In considering "alternative methods" of funding IR&D and B&P, it should be remembered that IR&D and B&P are indirect business expenses and should be fully reimbursed. In summary, full cost recovery of IR&D and B&P would place the US Government on an equal footing with all other customers. Anything less than full reimbursement of these costs, in effect, is a subsidization of the Government by American industry.

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COSTS AND TRENDS DATA

STATISTICS RELATING TO IR&D, B&P, AND OTE FOR MAJOR DEFENSE CONTRACTORS
(Millions of dollars)

| | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 1/ | 1972 2/ | 1973 3/ | 1974 4/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sales | | | | | | | | | | | |
| Total Government and commercial | 23,470 | 24,054 | 28,438 | 34,167 | 36,954 | 36,430 | 32,519 | 32,065 | 30,577 | 37,635 | 40,405 |
| Total DoD only | 16,442 | 15,644 | 17,889 | 21,371 | 22,275 | 22,692 | 21,315 | 19,568 | 19,117 | 21,148 | 21,690 |
| % DoD sales to total sales | 70% | 65% | 63% | 63% | 61% | 62% | 65% | 61% | 63 | 56 | 54 |
| IR&D | | | | | | | | | | | |
| Total industry cost incurred | 419 | 439 | 502 | 591 | 752 | 808 | 753 | 703 | 936 | 1,164 | 1,148 |
| Total reimbursed on DoD contracts | 199 | 198 | 224 | 277 | 333 | 389 | 376 | 354 | 392 | 441 | 457 |
| Amount reimbursed on DoD contracts | | | | | | | | | | | |
| As a % of total incurred | 47% | 45% | 45% | 47% | 44% | 48% | 50% | 50% | 42% | 38% | 40% |
| As a % of DoD sales | 1.21% | 1.26% | 1.25% | 1.30% | 1.46% | 1.73% | 1.7[illegible]% | 1.86% | 2.05% | 2.09% | 2.17% |
| B&P | | | | | | | | | | | |
| Total industry cost incurred | 252 | 277 | 315 | 338 | 387 | 426 | 414 | 428 | 469 | 553 | 546 |
| Total reimbursed on DoD contracts | 182 | 186 | 202 | 230 | 275 | 286 | 278 | 265 | 306 | 360 | 351 |
| Amount reimbursed on DoD contracts | | | | | | | | | | | |
| As a % of total incurred | 72% | 67% | 64% | 68% | 71% | 67% | 67% | 62% | 65% | 65% | 64% |
| As a % of DoD sales | 1.11% | 1.19% | 1.13% | 1.08% | 1.23% | 1.26% | 1.30% | 1.35% | 1.60% | 1.70% | 1.62% |
| OTE | | | | | | | | | | | |
| Total industry cost incurred | 182 | 237 | 238 | 292 | 252 | 178 | 151 | 0 | 0 | 0 | 0 |
| Total reimbursed on DoD contracts | 71 | 76 | 91 | 92 | 77 | 79 | 60 | 0 | 0 | 0 | 0 |
| Amount reimbursed on DoD contracts | | | | | | | | | | | |
| As a % of total incurred | 39% | 32% | 38% | 32% | 31% | 44% | 40% | - | - | - | - |
| As a % of DoD sales | 0.43% | 0.49% | 0.51% | 0.43% | 0.35% | 0.35% | 0.28% | - | - | - | - |
| Grand Total | | | | | | | | | | | |
| IR&D, B&P, OTE incurred | 853 | 953 | 1,055 | 1,221 | 1,391 | 1,412 | 1,318 | 1,131 | 1,405 | 1,717 | 1,694 |
| Total reimbursed by DoD | 452 | 460 | 517 | 599 | 685 | 754 | 714 | 619 | 698 | 801 | 808 |
| Amount reimbursed by DoD | | | | | | | | | | | |
| As a % of total incurred | 53% | 48% | 49% | 49% | 49% | 53% | 54% | 55% | 50% | 47% | 48% |
| As a % of DoD sales | 2.75% | 2.94% | 2.89% | 2.80% | 3.07% | 3.32% | 3.35% | 3.16% | 3.65% | 3.79% | 3.73% |
| Total incurred as a % of total sales | 3.63% | 3.96% | 3.71% | 3.57% | 3.76% | 3.88% | 4.05% | 3.52% | 4.59% | 4.56% | 4.19% |

SOURCE: Annual DCAA Report, "Summary of IR&D and B&P Costs Incurred by Major Defense Contractors"

1/ The data represents that for 84 contractors comprising 175 profit centers. The cost principles in ASPR have been revised to include in their definitions of IR&D and B&P certain technical costs not previously included. These changes have become effective and therefore separate data for these "other technical effort" will not be included in this and subsequent reports.

2/ The data represents that for 77 contractors comprising 167 profit centers. $32M of the costs is burden applied to IR&D and B&P for the first time by those contractors who had not previously burdened IR&D/B&P. $13.8M is the amount of IR&D/B&P applicable to foreign military sales reimbursed to the DoD.

3/ The data represents that for 83 contractors comprising 182 profit centers. Included in the data are sales of $1027.3 to foreign governments placed under DoD contracts but reimbursed to DoD by such foreign governments. The applicable IR&D/B&P recovered in these sales is $38.2M. $55M in the data represents burden applied to IR&D/B&P by the last of those contractors implementing the overhead requirement of DPC 90 dated 1 September 1971.

4/ The data represents that for 90 contractors comprising 236 profit centers -- an increase of 7 contractors and 54 profit centers due primarily to the addition of contractors with advanced agreement who previously were below audit thresholds. Included are the foreign government sales of $1353.5M with $42M of applicable IR&D/B&P allocable to these sales. There was little or no impact due to increased burdening in 1974 because full implementation of burdening as required by DPC 90 was completed by most contractors in 1973.

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# Report of the Defense Science Board

# Task Force on Federal Contract Research Center Utilization



February 1976





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

6

# Report of the

# Defense Science Board TASK FORCE

# on

# Federal Contract Research Center Utilization .

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

27 February 1976

TO: THE SECRETARY OF DEFENSE

THROUGH: THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

The Defense Science Board Task Force on Federal Contract Research Center (FCRC) Utilization has completed its review of DoD-FCRC relationships. The Task Force found that the FCRCs continue to provide, in appropriate areas, high quality essential services for the proper and efficient conduct of the mission of the Department. The report on the study is hereby submitted. The recommendations are summarized in the Task Force Chairman's memorandum to the Director of Defense Research and Engineering.

Solomon J. Buchsbaum
Chairman
Defense Science Board

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

# ABSTRACT

Under the auspices of the Defense Science Board, acting on the request of the Director of Defense Research and Engineering, a comprehensive review of the relationships between the Department of Defense and the Federal Contract Research Centers (FCRCs) has been undertaken. The specially selected Task Force was asked to *"assess the DoD-FCRC relationships and recommend steps that could be taken to improve the short and long term posture of DoD with respect to FCRC utilization".*

The Task Force carefully reviewed the several previous studies of the FCRCs, and supplemented these with its own hearings, interviews, and deliberations. The conclusions, which strongly endorse the current policy of Defense in the utilization of the FCRCs, are summarized in a Memorandum to the Director of Defense Research and Engineering.

The following report details the investigation and, in addition to the summary memorandum, includes a series of specific recommendations from the Task Force. Several addenda providing pertinent data on the current FCRCs are also included.

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# I. CHARTER

CHARTER

DEFENSE SCIENCE BOARD TASK FORCE ON
FEDERAL CONTRACT RESEARCH CENTER (FCRC) UTILIZATION

I. PURPOSE: To assess the DoD – FCRC relationship and recommend steps that could be taken to improve the short-and long-term posture of the DoD with respect to FCRC utilization.

II. BACKGROUND: The Department of Defense has used FCRCs for a number of years. They provide high-quality research and development to all Services and most Defense Agencies. They are closely controlled and often reviewed by Congress, DoD, Services, GAO, etc., because of the unique position they occupy in a competitive society. The DDR&E now believes it is time to review the FCRC-DoD relationship and develop short- and long-term plans relative to their use, if the continued use is deemed advisable.

III. SCOPE: The review is to encompass all nine DoD FCRCs.

IV. STATEMENT OF WORK: The group will make an assessment of DoD-FCRC relationships in light of the following factors:

How are the FCRCs presently being used?

How is appropriateness of work for an FCRC determined?

What alternatives to FCRCs are there?

Should DoD alter its diversification policy?

How can the FCRC-DoD relationship, both from an FCRC and DoD point of view, be improved?

The Task Force will make conclusions and recommendations pertinent to their assessment. Both oral and written reports are to be prepared.

V. GUIDANCE: Close coordination with Services, Defense Agencies, and FCRCs is desired. Travel by the Task force to secure first-based information is encouraged. The report will be completed by 30 November 1975.

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# II. SUMMARY – Memorandum

15 February 1976

MEMORANDUM FOR THE DIRECTOR,
DEFENSE RESEARCH AND ENGINEERING

THRU: Chairman, Defense Science Board

SUBJECT: Summary Findings and Recommendations: Task Force on Federal Contract Research Centers (FCRCs)

The FCRC Task Force, established by DSB to examine the relationship between the Defense Department and the FCRCs, has completed its investigations. We find that, with minor exceptions, FCRCs continue to provide high-quality essential services in appropriate areas for the proper and efficient conduct of the mission of the Department. We believe Defense should continue its present policy on their utilization and we make some suggestions for maintaining their current effectiveness. The nine centers designated as FCRCs, down by half from the number so designated at the time of the last DSB study on this subject, are each distinctly different and therefore broad generalizations are difficult to apply. Arguments for need must be considered individually and no common criteria can be established, owing to the diversity. Strength of the individual arguments will vary, depending on the criteria employed in making the individual assessments. A need for organizations of this type has not been unique to Defense. NASA, ERDA, and NSF all support similar facilities. Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Jet Propulsion Laboratory, and the National Center for Atmospheric Research are among the well-known counterparts to the DoD FCRCs.

Federal Contract Research Centers considered in the Task Force Study were:

Aerospace Corporation, Los Angeles, California

Analytical Services, Inc. (ANSER), Falls Church, Virginia

The MITRE Corporation, Bedford, Massachusetts

MIT Lincoln Laboratory, Lexington, Massachusetts

RAND Corporation, Santa Monica, California

Center for Naval Analyses (CNA/University of Rochester), Arlington, Virginia

Applied Physics Laboratory, Pennsylvania State University,
ARL(PSU), State College, Pennsylvania

Institute for Defense Analyses (IDA), Arlington, Virginia.

APL - Johns Hopkins Univ.

In an imperfect world, no given entity exactly matches in all respects every desirable attribute. However, as a group the FCRCs are pointed toward certain common desirable characteristics which are not generally matched by either government in-house agencies or industrial firms doing R&D. These organizations view Defense problems from a perspective completely different from that of either government or industry. We feel they provide a standard by which in-house and industry performers can be both compared and challenged. By all of the conventional standards we have been able to employ, and by testimony from senior levels of their sponsorship, the quality of performance of the FCRCs is high, their competence is broadly based and deep, and perhaps even more significant, a lasting historical reservoir of lessons learned is resident in them.

Our recommendations are formulated to assist Defense in maintaining the high quality of some of the FCRCs and to improve the effectiveness of all:

1. *We strongly endorse the current policy of Defense in the utilization of the FCRCs.*

2. The functions being performed are essential to the Defense mission; as a consequence, no abrupt change appears feasible so we do not recommend such action. We have, however, detailed various alternatives to the FCRCs in a rank ordering should Defense elect to phase out or replace the FCRCs.

3. We feel that the FCRCs situated in Universities are reasonably self-regulating and that their quality and size are a continuing concern of the University management. We think the involvement of Defense with the University community is important and should be nurtured. A management philosophy which continues to apply Defense focus to their work and which satisfies accountability standards for contract administration is about right. Overmanagement in detail is wrong.

4. The Study and Analysis FCRCs are most in need of a line item support concept of management which is permissive to a high degree as far as initiative is concerned. Placement of management control at too low an organizational level can defeat the purpose of the critical perspective needed to generate alternative command, and, in some cases, alternative service, policy advice.

5. MITRE and Aerospace, the two large, nonuniversity, systems engineering contractors should continue to be managed in their present single-contract mode at the level of the Commanders of ESD and SAMSO, so that setting of priorities is under the control of the agent responsible for the mission.

6. The current system of FCRC control by Congressional ceiling on internal operating costs appears to us to be outdated and inefficient, requiring far too much effort for the results obtained. While that control mechanism may have been necessary in the past, we believe a more useful concept would be an annual report of stewardship as recommended by the last DSB Task Force studying this subject. No further controls appear necessary.

7. Some margin for technical renewal and initiative must be provided in any management concept for these organizations. While the fee route, we agree, satisfies cash flow needs and plant and equipment renewal, at its current level as provided by the modified ASPR guidelines, it does not provide the government with an adequate independent planning and technological initiative. We believe some negotiated percentage of total volume should be devoted to FCRC-initiated research and planning tasks supporting the mission of the sponsoring agency. Costs for such relevant tasks should be considered as allowable and reimbursable costs in every contract arrangement.

8. All of the FCRCs exhibit some trends toward technical stagnation. We feel these trends, although not serious, should be ameliorated by planned technological renewal.

9. Diversification practice should be a subject of individual annual review by the sponsoring activity. Our judgment is that, on balance, Defense today has more to gain than it loses through diversification. The individual sponsor should satisfy himself that he is getting what he needs in undiluted management attention.

10. Staff salaries should continue to be allowed to move with the market for technical professionals as they do now. Average cost per member of technical staff and average salary per member of technical staff are not excessive by the standards we have been able to apply.

11. Our judgment is that the total current size of the FCRC family is reasonable and appropriate.

12. FCRCs are competitive, but in our judgment, rightly so. On the other hand, we believe that to avoid built-in conflicts of interest, no FCRC should be permitted to competitively respond to Requests for Proposal circulated to industrial sources.

We have made an oral report to your staff and we leave with the staff a comprehensive discussion-oriented paper with a more detailed treatment of the subject.

Robert A. Duffy

Robert A. Duffy
Chairman
Defense Science Board Task Force
on FCRC Utilization

# III. INTRODUCTION

## III. INTRODUCTION

The Director of Defense Research and Engineering has asked that a review be made, under the auspices of the Defense Science Board, of the relationship between the Department of Defense and the Federal Contract Research Centers. The review group is to assess the current status of this relationship, and as a result of this assessment, to make both short- and long-term recommendations on the utilization of the FCRCs by DoD.

Current DoD policy is to use the FCRCs to augment, or in lieu of, in-house Research and Development agencies in those areas where the special characteristics of the FCRCs best fit Defense needs; this is under close management control in the form of Congressionally imposed cellings on internal operating costs centrally administered as a bloc by the ODDR&E. A military service or a Defense Agency is specifically responsible for each FCRC. Congress regulates this control by an annual budget action specifying the amount of appropriated funds which may be expended for FCRC support.

The FCRCs are a special grouping of the National Science Foundation's classification of Federally Funded Research and Development Centers (FFRDC) which are devoted to Defense Department needs. The Report of the Commission on Government Procurement (COGP) dated in FY 1973 describes these organizations as operating under long-term commitments to Federal agencies to perform or administer R&D, systems management, or study and analysis. COGP states, *"the sponsoring agency has the responsibility for continuity of the center through funding its efforts and provides some degree of supervision of its activities".* These organizations are operated by nonprofits such as universities and independent research institutes or by nonprofit corporations.

The oldest of the existing FCRCs is the Applied Physics Laboratory at Johns Hopkins University, organized in 1942 at the request of the Office of Scientific Research and Development (OSRD). It gave central direction and technological support to an association of universities and industrial contractors developing new concepts for weapons systems. The variable time (VT) or proximity fuze for artillery and aircraft munitions was a prime output of this effort. Harvard University's Underwater Sound Laboratory, the MIT Radiation Laboratory, and the Jet Propulsion Laboratory at Cal Tech were similarly supported and administered during the war years.

In the post-World War II years, comparatively low government pay scales for professionals, a conscious desire to prevent a large permanent technical staff from growing in the new Air Force, recognition of a need for independent technical judgments, increasing complexity of new weapons systems, and high degree of specialization required in their development, led government agencies to seek support from outside groups of recognized experts. FCRCs grew out of this need in the three areas now recognized as broadly characterizing them – study and analysis, systems engineering and technical direction, and specialized laboratory organizations.

At least in some cases, these special organizations were formed to circumvent the bureaucratic delay inherent in government where critical-time weapons developments were the concern of the nation. At least in the case of the Intercontinental Ballistic Missile (ICBM) and the SAGE (Semi-Automatic Ground Environment) Programs, there did not exist in government, at that time, a broadly based systems engineering capability adequate to the task of organizing and directing those two very comprehensive efforts. Space Technology Laboratories (STL), the predecessor to Aerospace Corporation, and for SAGE, the MITRE Corporation were created to satisfy this need.

The COGP states *"these private institutions continue to be in a position to provide unique and valuable services to their sponsoring agencies. Because they have been successful in attracting many talented professionals, possessing special skills and expertise in a diversity of fields, they can offer the services of multidisciplinary. . .teams. Although largely dependent on the government agencies for their existence, they operate outside the government. . .and have an independent perspective. . . In principle, they are not tied to the particular sets of objectives and commitments that characterize the agencies, and their objectivity is not constrained by any profit or product bias that might arise in the profit motivated sector."*

The Congress has acted, in specific legislation, to curtail DoD's use of the FCRCs and to improve the conditions for government's acquisition of the professional skills and talents necessary to reduce the need for "outside" assistance in the work areas the FCRCs have covered. The Professional Services industry, a growing technical skill pool operating in the for-profit sector, has challenged the "special status" of the FCRCs, contending that government has an obligation to place *". . .maximum reliance upon the qualified for-profit performer"*. The National Council of Professional Service Firms, purporting to represent an industry of a $16.1 billion annual volume, in the same statement from which the above is extracted, states further *". . .the fundamental policy which should guide support of captive organizations such as FCRCs is to limit their activities to those for which the private sector has no competence or no existing capability. Where there exists no capability in the private sector and the government needs a service performed, this service may be performed in-house or through an FCRC initially, but at the same time, steps should be taken to encourage the private sector to develop such capability and to commence providing the required services at the earliest possible time".*

With this background, we address what we consider to be the key issues. Our findings and recommendations are formulated in that context.

# IV. METHODOLOGY EMPLOYED IN THE STUDY

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The Task Force made no effort to define an FCRC but accepted as the scope of the review those organizations considered by the Congress and DoD to make up the present family of DoD FCRCs. This included the following institutions:

Aerospace Corporation, Los Angeles, California

Analytical Services, Inc., (ANSER), Falls Church, Virginia

The MITRE Corporation, Bedford, Massachusetts

MIT Lincoln Laboratory, Lexington, Massachusetts

RAND Corporation, Santa Monica, California

Center for Naval Analyses (CNA/University of Rochester), Arlington, Virginia

Applied Physics Laboratory/Johns Hopkins University, APL(JHU), Silver Spring, Maryland

Applied Research Laboratory, Pennsylvania State University, ARL(PSU), State College, Pennsylvania

Institute for Defense Analyses (IDA), Arlington, Virginia.

In undertaking this review, the Task Force believed that it was important that both the FCRCs and the principal sponsors had an opportunity to express their views concerning the current DoD FCRC policy and to make recommendations to the Task Force concerning actions that should, or could, be taken to improve the efficiency and effectiveness of this approach to military R&D. In addition, public sessions were convened so that other than DoD personnel and/or organizations would have an opportunity to either advocate or oppose FCRCs as a means to meeting these objectives:

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| Air Force, Pentagon, Washington, D.C. – 2 June 1975 | (open session) |
| Navy, Pentagon, Washington, D.C. – 2 June 1975 | (open session) |
| WSEG, Pentagon, Washington, D.C. – 2 June 1975 | (open session) |
| IDA, Arlington, Virginia – 3 June 1975 | |
| CNA, Arlington, Virginia – 3 June 1975 | |
| APL(JHU), Howard County, Maryland. – 4 June 1975 | |
| ANSER, Falls Church, Virginia – 4 June 1975 | |
| MITRE, Bedford, Massachusetts – 5 June 1975 | |
| Lincoln Laboratory, Lexington, Mass. – 6 June 1975 | |
| RAND, Santa Monica, California – 21 July 1975 | |
| Aerospace, Los Angeles, California – 22 July 1975 | |
| ARL(PSU), State College, Pennsylvania – 24 July 1975 | |
| Open Session, Pentagon, Washington, D.C. – 25 July 1975. | |

The sessions with these organizations were structured to respond to a set of prepared questions (Appendix I) provided by the Task Force. This, however, was not a limiting factor and all parties were encouraged to depart from the format if they so desired. In addition, at laboratory installations where "hands on" R&D is under way, the Task Force visited laboratory facilities and were briefed on work under way to understand the nature and scope of R&D at the various institutions.

In seeking the views of the parties involved in the DoD FCRC interface, responsible officials of the visited organizations and/or institutions were contacted. Briefings and discussions were undertaken with Assistant Secretaries (Research and Development) of the Services, Presidents of the Corporations, and Directors of the Laboratories acting as principals for their organizations and supported by top management assistants and advisors. The interest of high management personnel facilitated the acquisition of information by the Task Force and ensured responsible responses to specific questions.

Of concern to the Task Force was the need to determine specific changes taking place, intentionally or unintentionally, in the use of the FCRCs with respect to the functions they perform. As a convenience, the breakout used by previous studies was employed: (1) Studies and Analyses FCRCs; (2) System Engineering/Technical Direction FCRCs; and (3) Laboratory FCRCs.

The Task Force found that the Studies and Analyses FCRCs (RAND, IDA, ANSER and CNA) perform essentially the same type of work for the DoD (logistics, resource analysis and allocations, force structure, requirements evaluation, etc.) as they have provided to DoD over the past decade. However, there is a significant reduction in the number of professional staff members used by the DoD for this activity. The total decreased from approximately 975 professionals in 1967 to about 660 in 1975. The preponderance of the reduction was at RAND, but reductions also were significant at IDA and CNA. The Services and other sponsors continue to consider the Studies and Analyses FCRCs to be their best source of high-quality, independent professional judgments available for use in the decision process.

The System Engineering/Technical Direction FCRCs, Aerospace and MITRE, are continuing to provide the major portion of system engineering support to the Air Force Space and Missile Systems organization and the Air Force Electronic Systems Division, in lieu of in-house support. MITRE's effort, in terms of professional staff, to DoD has remained essentially constant over a number of years. However, Aerospace has declined about 28 percent since 1967. The loss has resulted in Aerospace Corporation becoming essentially a space system engineering support organization to the Air Force. The missile engineering function has been assumed by other, nongovernment organizations. A second transition, not precisely definable, is the transition from System Engineering and Technical Direction organizations to primarily Systems Engineering organizations. The Technical Direction function has declined substantially at both MITRE and Aerospace. A third change has been the decrease to a near zero level of the planning function provided by Aerospace and MITRE to their primary sponsors. The Air Force strongly endorses these FCRCs and the flexible manner in which they respond to Air Force needs. In addition, the lesser sponsors have high regard for the quality of these organizations. This creates a "demand" for additional use of Aerospace and MITRE that cannot be provided at this time because of overall ceiling limitations on FCRCs.

The Laboratory FCRCs [Lincoln, APL(JHU) and ARL(PSU)] have remained basically unchanged in size, with a collective professional staff that has neither grown nor dwindled significantly since 1967. All of the University laboratories have extremely close ties with their parent school and, although responsive to DoD needs, accomplish this goal within the broad policy guidance of their respective Universities. They continue to provide highly productive and innovative work for the DoD and have been most flexible in meeting changing operational and/or technological challenges. The facilities and equipment of these institutions have kept up with the times and provide excellent background for the acquisition of highly qualified professionals. The Services and other sponsors depend heavily on the Laboratory FCRCs for a relatively small but important portion of their laboratory R&D.

The Task Force had the opportunity to review and use previous studies conducted by various groups during the past 10 years. Principal references used by the Task Force were:

- DSB Task Force on Federal Contract Research Centers, 24 October 1966 (Alpert Report) *received*

  An Assessment, The Need for, the Roles of, and the Alternatives to the Use of MITRE and Aerospace, 3 October 1968 (Terhune Report) *received*

  Report of the Special Study Group on Federal Contract Research Centers, 30 August 1971 (Harwood Report) *received* *AD A007 065*

  Statement by the Director, Defense Research and Engineering before the ad hoc Subcommittee on R&D of the Senate Armed Services Committee, 5 April 1972

  Final Report on Air Force Federal Contract Research Center Sponsorship, October 1974 (Small Review Group). *received*

These reports, plus other material developed for the evaluation of FCRCs, provided the Task Force a baseline upon which to make considerations without the necessity of redoing much of the effort undertaken by the previous study groups. The Task Force acknowledges the values of this past work in arriving at its recommendations and conclusions.

*message left to her on 4/5/77*
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# V. DISCUSSION OF ISSUES

## A. NEED FOR FEDERAL CONTRACT RESEARCH CENTERS

At the risk of some repetition of remarks made in the introduction to this study, some historical context is necessary to an understanding of the *need* issue with respect to the FCRCs. During World War II, desire for the involvement and active participation of the scientific community in decision making and in solution to real problems experienced by the government in the conduct of the war led to formation of FCRCs. The Radiation Laboratory at MIT, the Underwater Sound Laboratory at Harvard, and the Applied Physics Laboratory of Johns Hopkins were the progenitors. The need for the "honest technical broker" attitude continued after the war as a full realization of the complexity of the new technology and its impact on the military, and the civilian management of the military, became evident to the decision makers in government. They sought out, or created, the study and analysis talents of the not-for-profits such as RAND and IDA to satisfy this need. Finally, although professional engineering services and scientific assets were present in the government civil service and military ranks at the time, the Ballistic Missile programs and the Air Defense Electronics programs were too large and too complex tasks for the Air Force to accommodate within its internal resource structure at that time. TRW/Space Technology Laboratory, with hardware manufacturing exclusion, and MITRE Corporation, a not-for-profit, were created to systems engineer these two program families. Aerospace Corporation replaced STL under Congressional pressures questioning the propriety of a profit-seeking corporation in this role. Paralleling the DoD pattern, the AEC managed its weapon development activity through the auspices of the University of California by the establishment of the Los Alamos and Livermore Laboratories.

The characteristics of the FCRCs noted above were judged at the time to be vital to the roles played. In general, detachment from day-to-day operations, the absence of proprietary manufacturing prejudices and concomitant financial considerations, the technical excellence and dedication of the people in research at university centers, and the absence of military service biases, tended to influence the decisions in what were judged to be purely technically dictated terms. It was also felt that renewal of vitality and quality could better be assured in the management environment of the not-for-profit corporations. Finally, and very importantly, a priceless memory could be, and was, stored in these organizations' cataloging of lessons learned over a very broad and deep spectrum of events and circumstances.

Changes have occurred since the inception of the FCRCs. Federal salary structures have changed upward, military and civil service personnel have been schooled in the new technologies and in modern analytic methods, and a total industry in technical services has been born and is growing in the private sector. These factors and others have led to an average of one study per year on the subject of either the need for, or the management and control of, the FCRCs.

Perhaps the most telling criterion for judging need is the expression of demand. All FCRCs involved in this survey were, in effect, oversubscribed. In every case, we found positive statements of need and expression of intent for continuing sponsorship and support on the part of

DoD agencies concerned. Not all specific statements of need were free of criticism of the FCRCs emphasis on sponsor priority of effort nor in every case did we find precise agreement on detailed roles. In no case did we find any suggestion that, in the short term, the mission of the sponsor could be performed without the service the FCRCs are now providing. On the other hand, almost universally, statements were made to the effect that the mission could, in time, be performed by alternative methods. Since we have ample evidence that this latter case is, in fact, true, one then must make value judgments as to relative merits for the longer term solution in various forms. In the case of RAND and to some extent ANSER, CNA, and IDA, the issue becomes one of perspective. Can one describe a problem to another agent in a sufficiently detached manner so as to provide objective analysis free from the influence of sponsor viewpoint and prejudice? At what level organizationally would one introduce the product of this analysis? Does the need in itself create characteristics of the performer? Could one expect detached treatment from a performer with organizational loyalties, memory and aspiration related to his product? In the case of the product-related FCRCs – APL(JHU), ARL(PSU) and Lincoln Laboratory/MIT, the need issue is more broadly related to their total environment. The academic and research orientation of these institutions, their special facilities and people, and their divorce from proprietary-product interest in manufacturing is attractive to their Service sponsorship because of the creative totality the institution itself represents. The large Systems Engineering agencies, MITRE and Aerospace, are a more difficult case to substantiate in a need sense over the long term. No question is raised as to the basic need for the function both perform. Both were created at a time of acutely perceived need when industry was judged either to be incapable or politically unacceptable as satisfiers of a real need. The case for these two agents needs to be considered at least in terms of start-up costs. They exist, their function must be performed, and a cost is entailed in converting to any other form for satisfaction of the need. Civil service organizations do perform similar functions elsewhere and one answer in the long term would clearly be the establishment of such an agency. Military organizations, on a lesser scale, have accomplished complex tasks with some similarity to those performed by the FCRCs and that solution is an option. The establishment of suitable billets and the recruitment in depth of qualified personnel to fill the billets could prove troublesome in these two latter cases. Private industry, with suitable restrictions, can and does perform similar roles. On the other hand, no clamor has been noted for new additions to the FCRC list and these restrictions on management freedom have had, at least, that effect. Some transient effect will, in every case, be encountered in any conversion. A new "special relationship" will have to be established. A time of overlap and a proper, careful, transitional phasing will need to be arranged. Finally, some arrangement for the establishment of a new corporate memory and the transfer of the old memory will be essential if minimum impact on mission is to be expected. It is doubtful that this corporate memory can be provided on an across-the-board basis in a major field of endeavor by competitive industry – without having the Defense Department provide an unfair advantage to the company that would have access to all of the information required to perform this function effectively.

## B. APPROPRIATENESS OF FCRC WORK ASSIGNMENTS

A continuing, frank, intimate, and privileged working relationship between sponsor and performer is probably the single common attribute one can make for the FCRC. The special relationship so created is not a unique FCRC/Sponsor characteristic; government agency/industrial contractor intimate relationships do exist on some critical programs. This intimacy may also be the occasion for the largest body of criticism about the FCRCs. It gives the appearance of favoritism to the critic who feels outside the family when government procurement actions have eliminated him from an award. The critic construes the action as having been influenced by advice received by the procuring agent from an FCRC; perhaps, too, he sees work being performed by the FCRC for which he feels qualified. In both cases, he is frustrated and the FCRC is the common element. Since taxpayer resources are involved, his recourse is to the executive department appointed official or to the Congressional element responsible for oversight and appropriation. Is the government interest best served, then, when this challenge to its conduct of affairs in the public interest is constantly brought to its attention?

The consensus of prior studies to which we have had access was:

(a) It is in the DoD's interest for each major DoD component to do its own decision making, but to have at least one intimately related study and analysis capability outside its command structure. This allows objective challenge to be offered the decision maker to sharpen his views of the advocacy position taken by his in-house agents.

(b) A combination of in-house R&D activities, industrial muscle and technical capabilities, and the unversity-related laboratories, provides both a mix and a control, which strengthens the overall defense R&D community and provides the comparative performance necessary to give options for choice to the Government on how best to perform a given task.

(c) Some jobs at some times are too complex for government to handle in-house and, at least in their early stages, are not appropriate to assign to industry unless suitable safeguards are applied to protect the competitive process, especially when very large procurements are involved. On the other hand, when government feels it must act, no job is too big. Apollo is an obvious example.

We believe the privileged status of the FCRCs is in fact privileged — both with respect to government *and* with respect to the industrial performers who must provide the final products, the systems to perform military missions. Some performers must be so privileged or the work done will repeat steps long resolved and unnecessary and wasteful expenditures will be made, perhaps even on an ultimately faulty premise.

Why can't this privileged access work be accomplished within the permanent resources of the Defense Department? In most cases, where resources exist, it *is*. The report of the Commission on Government Procurement (COGP) covering all aspects of government's "Acquisition of Research and Development" makes comparisons showing that of the $15.5 billion of the analyzed year's Federal R&D budget, over 25 percent was expended at in-house facilities. In the case of Defense expenditures during that year, 25 percent was expended at in-house laboratories. The share of the same budget expended at FCRCs was about 3 percent, leaving the bulk of the remaining R&D expenditures, most of which were not in the privileged class, for all other performers. Industry was by far the largest recipient of all Defense R&D funding in that typical year.

If the difficulty of providing in-house resources in adequate depth and span of talents and quality is as typically reported in the AFSC Terhune report of 1968, the report of the Air Force Small Review Group of 1974 and the Congressional testimony of the Director, Defense Research and Engineering, then the possibilities of privileged source on a continuing basis narrows down to two reasonable choices, both select groups: a safeguarded segment of industry or the FCRCs. Select industrial activities have performed in this role before, where systems engineering is the primary product and safeguards satisfactory to the Congress have, in general, been negotiated. It is likely that with mature development, this practice can (and should) continue.

On the other hand, for policy guidance, and as a check on and critique of advocacy positions, the case for the industrial agent becomes less clearly desirable. Since memory in the system is an important quality and cost factor in continuing analysis and study activity, the tendency is strong that single preferred performers would emerge as captors of a given procurement agency's awards for a given area. In this way, a new "corporate memory" in a mission area would grow, and the tendency, for sound economic reasons, would be to reprocure from the same performer/supplier. Either the profit-seeking industry, not so privileged, or the Congress would surely react to this "favoritism" if past experience is a guide.

A different consideration with respect to the appropriateness of awards to certain of the FCRC performers is the nature of the interrelationship which grows between performer and sponsor with respect to policy advice. Can a contracting agent at a level deep in a command influence the product of a performer whose advice is targetted at the top of an organization? How do cross-command problems get resolved objectively if one command controls the purse strings with respect to the generation of policy advice? An advertised procurement with open bidding for study activity of this nature might be extremely unwieldy to handle also. Therefore, the total relationship between the performing member, his total working environment, and the nature of the task to be performed are factors to be accounted for in the appropriateness judgment. Any given task taken as a singularity could well give the appearance of an inappropriate award;

yet when judged in total, with the factors noted, this may not only be appropriate but singularly so. It is not clear to the review group how one can make this point in a convincing manner to the critics of the FCRCs.

There are obvious cases where effort in R&D outside the privileged field or within the resource capacity of the government itself should not be awarded the FCRCs. Since the amount of such activity appears to be approximately 97 percent of the R&D budget (as reported by the Commission on Government Procurement) – and all of the non-R&D budget – it would appear that the government procuring activities are able to make this distinction. It would be important to make a further investigation to determine whether work that would most appropriately be assigned a privileged performer were – in fact – because of controls applied by the government through FCRC ceilings or Civil Service limitations – assigned to a performer who was not best suited for the task because of inherent conflict of interest. Are we, in fact, penalizing ourselves with unrealistic gates through which a procuring agent must pass? It is as true today as it was when the FCRCs were first established that government, Defense certainly, is faced with many complex issues needing objective and qualified analysis, and technical supervision. The perspective from which an issue is addressed can have an important effect on the insight provided by analysis. Finally, the conflicts of interest created by performers having a stake in the outcome, even if not real, but only apparent, would encourage the involvement of disinterested, qualified and properly motivated performers in some aspects of government activities. We wonder, in fact, whether the current 2.5 percent budget commitment for the FCRCs is adequate?

## C. CONTROLS

The Congress of the United States, the Department of Defense, the individual Services, Corporate Boards of Trustees, and in some cases (usually university parents), government bodies above the individual Federal Contract Research Center (FCRC) all exercise some form of control over the special form of nonprofit organization termed FCRC. Ten years ago these institutions numbered 18; at the time of Dr. Foster's report to the Congress in 1972, the number was 12; and at the time of study by the currently constituted review group, 9 institutions made up the list. The total professional manpower devoted to Defense issues by these performers has been reduced. The salaries of executive managers and key technical leaders have been legislatively limited. Personnel paid above a given salary level are reviewed and approved at a central government level above the contracting agency. Individual tasks are negotiated to the level of the nearest tenth of a man-year and government audit agencies have resident government personnel in contractor activities.

Particularly in the case of the SE/TD performers, what have not been matched in a control sense appear to be requirements and resources. From all sources – military, civil service, industry and the not-for-profits – a best fit between fluctuating work demand and resources available and directed on prioritized tasks has not occurred. The major fields we examined were in military space and command, control and communication. We saw clear evidence of Air Force switching resources within Aerospace Corporation from ballistic missile to space activities to accommodate to new requirement priorities in Navy and Air Force interest. On the other hand, we also noted that, notwithstanding these changes, the application of the FCRC resources was inadequate to meet demand. No additional civil service or military technical resources were available to fill the gap. While industrial resources have been used in selected procurements, the controls applied to the overall FCRCs resource are such that very large commitments of funding are being made with what might be shallow engineering oversight. The situation at MITRE appeared to be similar, except that the Air Force does have resources, and is, recently, augmenting the military and perhaps the Civil Service technical staffs at the companion Electronic Systems Division of the Air Force Systems Command.

A possible control scheme, which might be useful in such a set of circumstance, might be one keyed to the systems program resources. As new major systems acquisitions are initiated, one could provide a given percentage of the systems program budget to the systems engineering function, dependent on program complexity, and permit the associated FCRC level to fluctuate with program progress. Further modification of the FCRC level, where military or civil service support is available, could be (and has been) effected through the Defense Department management resources as delegated. In all cases the control for this negotiated level of support should rest with the mission-responsible agent in government.

On a reduced scale we saw evidence of similar constraints at Pennsylvania State University with respect to the Navy lightweight torpedo program, and at Lincoln Laboratory with respect to Navy laser and other activities. In both cases a further restraint not tested on these specifics is the stated policy of the parent against expansion.

The current control scheme by ceiling appears too rigid to accommodate to the exigencies of the situation. Placing the authority to exercise these controls at the level where the mission is to be performed appears to be appropriate. A report of stewardship on a regular basis would provide overview management an opportunity to test the adequacy of the control at the responsible level.

## D. SIZE & GROWTH

What is an optimum size for a FCRC or what growth rate should be permitted to maintain momentum within the organization so classified? Is the characteristic of growth a proper criterion of goodness and success for all organizations? One view holds that stably managed entities will never exhibit the verve, elan, and enthusiasm of the growing, changing unit. Creative, original, innovative people thrive on change. Is there some characteristic of the FCRCs work area that would permit attracting these people in a nongrowth environment? The current control concept does dictate level or, in most cases, declining resource management in behalf of the Defense Department mission.

The congressionally established ceilings for the Department of Defense for the FCRCs has not inhibited total growth. Some of the FCRCs have grown since the constraints have been applied. Others have chosen to diversify to stabilize overall size rather than to shrink. Some have done neither. What other constraints are there on size and growth?

First of all, there is a minimum size for any mission. Each skill area must have adequate representation. The depth to which program areas can be worked will depend on manning. The impression one has is that the increased and forecast increasing utilization of the space medium to extend capabilities in the tactical field of operations will tax the current resources of Defense to accomplish its missions. Similarly, not enough capability exists to perform the architectural tasks and the scoping and unification tasks needed in systems engineering command, control, and communications systems currently planned for acquisition if the 5-year forecast on funding to be applied to this mission area is a true reflection of the activity expected. Either an in-house systems engineering capability will have to be grown, the Lincoln Laboratory, and MITRE and Aerospace Corporations will have to expand, or some methodology for placing that function in the hands of industry will have to be devised in the face of the Congressionally imposed restrictions on hardware-supplying agencies regarding their SE/TD activities.

In the case of the university-controlled FCRCs, our observation is that the stability evidenced over the past 5, or 10 years in these organizations indicates that the trusteeship and the operating management of the universities involved felt that those activities — Lincoln Laboratory, Pennsylvania State University Applied Research Laboratory, Johns Hopkins Applied Physics Laboratory — were about the right size in the university community. These laboratories have been reasonably self-regulated.

The study and analysis FCRCs have followed a pattern more closely akin to the university laboratories than to the systems engineering organizations. We believe this to be a manifestation of government controls, except for the RAND Corporation which had begun a trend towards some growth through diversification long ago. Again, however, in RAND's case, there is clear evidence of manpower-level modulation downward with respect to Air Force activities as a consequence of the Government's active control. The modulation in growth applied by the Service agencies, for whatever reason, is clearly evident and all FCRCs show some effect of this.

A concluding observation might be that growth appears to us to be a noncritical element in the equation of utility as far as Defense is, or should be, concerned. The university laboratories are self-regulated to a very large degree and only minor control attention appears to be needed from outside forces. The study and analysis FCRCs are growth controlled adequately by their Service sponsorship now, and their avowed independence will tend to restrict growth in their traditional roles. Who needs too much criticism from paid critics? On the other hand, where advocacy of a sponsor's course of action is the product, as in the case of the SE/TD contractors, the planning and study activity should probably be regulated as a percentage of total effort. One growth-modulating scheme could be a phased elimination of FCRC support on mature systems by prearrangement so that Industry performers move into activities behind the FCRC and the scarce resources in intimate contact with the Service sponsor move on to new systems activities. Major fluctuations in size of these SE/TD FCRCs could be one consequence of this scheme. The turnover in personnel, in depth, would be beneficial in a renewal sense. The "corporate memory" would have to be guarded by some combination of some line item like support covering laboratory-like and planning activities.

## E. QUALITY

A characterization of the FCRCs frequently quoted is that they bring to the Government's service a quality impossible to attain within government. Since all FCRCs have differences in mission, we find differences in personnel characteristics and professional qualification. This same statement is true with respect to industrial and government research and development activities. The generalization can be supported to a degree by comparing academic qualification of professional personnel. The FCRCs as a whole tend to have a significantly higher proportion of their professionals holding advanced academic qualification, and of those holding advanced degrees, roughly twice as many doctorates appear on the FCRC roles as appear on the roles of the Defense Department in-house laboratories. Another generalization which probably has truth in only some cases concerns "hands on" experience. Lincoln Laboratory, Johns Hopkins Applied Physics Laboratory and Pennsylvania State's Applied Research Laboratory clearly can make this distinction. Aerospace and, to much lesser extent, MITRE have research operating activities, but to a very much lesser degree than the university laboratories – certainly some government laboratories have comparable levels of "doing" activity. The study and analysis FCRCs have essentially no such distinction.

A method for acquiring familiarity with developing technology could be a turnover which brought into the system new faces from an active industry or from the university research activities. All performers exhibit some of this mobility; it is higher for the FCRCs than what we would expect the government organizations could experience. As one might expect, the rate varies dependent on the characteristics of the organizations. On the average, the annual turnover at the FCRCs has been about 10 percent over the past 5 years. For some activities, the "hands on" laboratories, this rate appears reasonable. It may not be so for the system engineering FCRCs. In the same vein, it is important to note that in-service laboratories are experiencing an increasing change rate, largely occasioned by the rate at which civil servants are retiring. An encouraging trend in qualification for the in-house activities is also to be expected as a consequence of the much more favorable pay rates professional civil servants can expect now over those of former years. This turnover is occurring more frequently now at all levels in government laboratories.

Finally, the tone, forcefulness and competence of the leadership may be a vital factor in establishing the quality of product in any organization. The total environment of the FCRCs comes through in general as a net plus for Defense on this score. On the other hand, where this element is weak, the impact is immediately evident. Should a continuing involvement with FCRCs be desirable to Defense management, it may be important to consider some method for rotation at the top levels of management. Since the very independence of these corporations is a sought-for attribute, it is not clear how this might be accomplished. It is worth a study.

## F. COSTS

In examining the costs of the functions performed by the FCRCs, three fundamental cost items were examined. These cost elements were the salaries of the members of the technical staff, the largest single element of the costs involved; the overhead or support costs to enable the members of the technical staff to function properly; and facility and associated costs. There are also a large number of myths, some differences in standards of accounting, and a number of hard-to-quantify costs which complicate any cost comparison in depth. Finally, there is a judgmental factor which may be even more significant in costs judgments than all of these mentioned above. How much technical direction and systems engineering is necessary to adequately perform with proper assurances the complex task of producing new, better and more efficient national security systems?

On the subject of salaries for technical staff members, we noted that in general the costs associated with salary for staff members were normally those necessary to meet the market for the talents represented by the various technical staffs within any given market area. Staff (MTS) salaries, in general, were in line with industrial salaries in associated industries, but were equal to or lower than comparable government salaries paid for the same functions. In examining support costs, salary level and overhead percentage on the basis of direct salaries and wages we found roughly comparable in all elements of the industry. It was not possible for us to make similar comparisons with government agencies. On the question of facilities costs, we note that there are some investments in unique and highly specialized facilities at a number of the FCRCs we visited. Two examples are cited: the 48-inch water tunnel at Pennsylvania State University used in torpedo research is a "one of a kind" facility that would either have to be moved or manned by a contingent of personnel from another performer, such as the government itself or a for-profit agent, on the current site if the same functions are to be performed for the sponsors. The circumstances of an interested and competent faculty and an involved university administration might be difficult to duplicate. Similarly, the Lincoln Laboratory has built and operates unusual facilities associated with radar and laser propagation properties. Again, the proximity of the facilities to MIT and its involvement with faculty and research staff would be a difficult circumstance to duplicate. Both examples imply added costs with any changes.

Some of the myths that have grown up about the FCRCs center on these cost factors. As an example, critics in citing the <u>cost</u> of an MTS frequently quote the salary of an MTS, forgetting that a task has been negotiated in a contract which may have very large support requirements. The critic does not see the difference between contracting for a performed task in total and job-shopping a body. All performers, including at times FCRCs, buy bodies to relieve program pressures on a short-term basis and they do, in fact, buy them at nearly the MTS salary cost. On the other hand, in buying a <u>task</u>, the procurement agent has to describe the nature of the work required and he pays about what the market demands for that performance. Only incidently is the number of technical people involved used as an accounting measure for sizing tasks. Since FCRC overhead as a percentage of direct cost was comparable to, or lower than, that we see in the for-profit industry for similar functions, we can see no appreciable or significant differential in cost related to this factor for any reasonably competent performer.

Another myth is that associated with individual staff and executive salaries. We found no evidence to indicate that the average salaries paid by the FCRCs were any different for comparable quality people from those paid by any other performer. As a matter of fact, in some instances, we found government salaries for comparable levels slightly in excess of the salaries paid at the FCRCs. There is an obvious exception to this comparison where executive levels of compensation reach the Congressional limitations.

We did examine fees paid FCRCs and find that the weighted guidelines employed in fee negotiations with not-for-profit organizations as modified from ASPR do result in fee structures which appear to us to be reasonable, and about half those traditionally paid the "for-profit" industry. Some management freedom is essential to cover the acquisition of needed facility and equipment items to conduct contracted research and for attacks on future problems. Transitions between major program onsets and demises require some management flexibility too. There appears to be no practicable substitute for fee. It should be noted that the ASPR-modified weighted guidelines do take into account the income tax factor in establishing fee for not-for-profits.

A final point on costs has to do with cost competition on contracts that can be reasonably completed. The for-profit industry performer can exercise judgment as to quality of people and, in some special cases, overhead rates to be applied when he bids on well-understood procurements. On the other hand, the memory in the government's procurement system must be well established and adequately manned or the savings on one task may well be lost many times over on subsequent tasks. The final judgment on the suitability of competitive jobs probably can be made only on an individual task basis. The complete environment of the FCRC performer is a factor to be taken into account in this respect. The availability of a seasoned and informed team with memory in the system should have a beneficial effect on cost to the Government. The presence of other forms for accomplishing the function provides a measure of relative efficacy.

## G. DIVERSIFICATION

Diversification has occurred in a majority of the FCRCs in one form or another. A few of the FCRCs have not altered their basic sponsorship since their inception. The ranges can be represented by approximately a 50 percent diversification in the case of the MITRE Corporation and RAND in other than traditional sponsorship, and the Pennsylvania State University Applied Science Laboratory and the other study and analysis FCRCs would be the other extreme where essentially no diversification has occurred.

Like every other issue discussed, there are two sides to this argument. On the one hand, constraints applied as ceiling dollar volumes have not been maintained at an annual rate comparable with the rise in the cost of doing business. The result has been an economic bind within the Federal Contract Research Centers to the degree that, after reasonable economy measures were applied, the only remaining freedom for management action has been the lay-off of members of the technical staff. This is occurring in some FCRCs. Others are converting their staff to new areas closely associated with the problem-solving capabilities the FCRCs have built. Their argument is that, although they are special agents of the Defense Department, they are not completely captive by Defense. A bright group of people encouraged earlier by Defense to seek support or apply talents, depending upon one's viewpoint, at agencies other than Defense — where very complex problems are facing government outside the field of Defense — have found a market for their services. The consequence of these forces has been a varying mix of sponsorship for the FCRCs.

Two supporting arguments are offered as representing gains accruing to Defense resulting from diversified activity (other than the direct services of a competent team to solve problems for other government agencies). These supporting arguments are: (1) the spread of the overhead costs over a base that includes a large number of sponsors reduces the expense to any given sponsor, and (2) although Defense has a limitation of funding available to be expended in the FCRCs, other agencies do not, and Defense is a net gainer by having their experienced team exercised to keep their skills sharp on problems requiring the skills assembled by Defense. Some mobility is provided management between Defense and non-Defense areas of support. There are obvious truths in these arguments.

The counter arguments to the issue are: (1) the divided attention of management degrades the effort applied to Defense, particularly since a growing activity will require more management attention than a stable activity, and (2) an unfair advantage accrues to the FCRCs over the competitive profit-seeking industry. That argument is developed through statements that a floor or core of support is provided at known levels for predictable time periods by Defense, permitting management of the FCRCs to concentrate their efforts on the acquisition of new capabilities, and generally these new capabilities awards are made on a negotiated, noncompetitive basis.

On balance and in the context of the overcontrol observations made under C above, we have no compelling argument to make against diversification, if the sponsor can satisfy himself that diversification in the FCRC does not constrain him in the conduct of his mission. Further, he should satisfy himself that diversification does not dilute the ability of the FCRC to support that mission in the future. We believe, therefore, that today diversification is not a critical issue, and if any effect is felt, it is more a gain than a loss. Since these conditions can change with time, it would probably be best that the current Defense practice be reviewed annually to be assured that the balance does not tip unfavorably.

## H. COMPETITION

One issue specifically raised by critics of the Defense Department's relationship with the FCRCs is that termed "unfair" competition with private for-profit performers. The point is made that FCRCs operate from a privileged "special" relationship, and that Defense procuring activities take advantage of this special relationship to circumvent the Armed Services Procurement Regulations for their convenience, thereby losing the advantages to be gained for the Government in cost competition.

To put this issue into perspective, one must first note that approximately 2.5 percent of the Defense RDT&E budget is expended internal to the FCRC performers. The largest fraction of the Defense R&D budget is expended through the private for-profit industry, and all of the larger procurement budget is so expended. On the other hand, in detail, it would be difficult to conclude that at some time, under some circumstances, a government procuring activity would not take advantage of the possibility of short-cutting procedures to place perhaps a time-critical study at an FCRC activity for convenience. Much more likely, however, is the fact that the total environment of the FCRC body of intimate knowledge and its corporate memory of the Government's experience in a given field or area of activity make it the proper choice for some sensitive, time-urgent, or background-peculiar study before industrial or other performers can be included.

FCRCs should, in our view, compete with all performers on new ideas which are self-generated. We find clear evidence of such competition between FCRCs, for example, on communication satellite concepts and technology (MITRE/Aerospace/Lincoln). Basic navigation-satellite-based systems concepts have benefitted in a marked way by competitive study, technology development, and concept formulation between the Aerospace Corporation/ Johns Hopkins Applied Physics Laboratory and the Naval Research Laboratory. Lincoln Laboratory is conceptually and technologically in competition with Aerospace and other performers in reentry technology, particularly with respect to penetration aids. Pennsylvania State University's Applied Research Laboratory competes on a healthy basis with Navy in-house activities on torpedo concepts and technology. Many times a challenge to industrial sources can, and should, be made by both the FCRCs and in-house activities, where solid differences of technical judgment can be based on fact generated competitive to the industrially posed solution to a given problem. Without this challenge to the industry, the possibility of oversight in critical areas and consequent bad procurement, is, in our estimation, appreciably higher than prudent regard for the taxpayer's interest and, more importantly, the nation's security should permit.

There is a family of procurement activities where Defense should not permit the FCRCs to compete in our opinion. These procurements are those resultant from circulated requests for proposal (RFP). It seems to us that once Defense has decided that it can completely describe the intended procurement action and judges that all performers can be polled, the FCRCs should be excluded. Obviously, any procurement with a repetitive or production motivation should, in like manner, exclude the FCRC performer as an inappropriate source.

# VI. OVERALL IMPRESSIONS

## VI. OVERALL IMPRESSIONS

As a consequence of the review group's activities at the request of the Director of Defense Research and Engineering, we have formed the following major impressions about the issues we have perceived in our own deliberations or have been directed to address in the charge to the committee:

1. FCRCs currently provide a valuable and different perspective to the solution of complex problems, from the study through the systems application level, in the conduct of Defense R&D. The present need for their services is clearly stated and, in the short term, we see no alternative.

2. The quality of the FCRC staff has remained high, and perhaps improved, with respect to time and in comparison with the industrial and in-house performer in like roles. The total environment of the FCRC/sponsor relationship enhances quality.

3. The costs of the services rendered by the FCRCs remain competitive with the costs of all other performers in like roles. A judgmental factor, difficult to quantify in the case of the SE/TD performers, complicates this observation somewhat and leads to the question: How much technical supervision is needed for what tasks?

4. Controls applied by the Government to the FCRCs may be more harmful than helpful to Defense. On the other hand, the need for some control has been demonstrated in the past and is, to some degree, still evident.

5. Diversification in the work of the FCRCs into fields not related to the DoD programmatic effort is a troublesome trend. It clearly has benefit to Defense in some reduction in required support and in stimulation to the staff. However, it has the attribute of dividing management's attention and it sometimes creates pressures from the professional services' industry. It benefits other Government agencies. In sum, we believe that for now, the net gain is in favor of Defense and we agree that the locally responsible Government contracting agent should be in control. An annual review of the practice at the DoD level should maintain perspective.

6. The requirement for a nonaligned, qualified, but solidly grounded, informed, and continuing performer in analysis and the generation of policy advice without involvement in command line appears to be well established.

7. The review group examined mission responsibilities, and in some cases, their definition appeared to be lacking to a degree which could be important in output quality or appropriateness evaluations. MITRE gave a diffuse and less responsible impression in that context to the group than did others. Lincoln, while superb in quality and in some management attributes, left questions in our minds concerning where the talents were really directed by its sponsors. IDA, CNA and ANSER were difficult to distinguish from their sponsorship, although it is clear that some independence from sponsor comes through. These factors, if real rather than impressionistic, may be more sponsor-related than performer-related in all of the cases cited. Pennsylvania State's ARL and the Aerospace Corporation seemed clearly in focus. To somewhat lesser degree, Johns Hopkins and RAND concentrated along known mission lines with respect to their principal sponsorship, but diffused with respect to secondary sponsorship.

8. FCRC leadership differences were evident in the responsiveness and responsibility exhibited by the organization.

9. In all cases, sponsor enthusiasm and expressed need for the FCRCs were clearly evident.

10. Privileged relationships are necessary, although not unique to FCRC.

11. With difficulty over a period of time, and at some increased cost in the interval, all FCRCs could be either converted to some other form or eliminated. Defense could perform its mission in the area associated with FCRC support through different agents. The function these agencies perform, however, is crucial to an effective Defense.

12. Mobility and renewal, although better than that which the civil service exhibits, is still not good enough overall in the committee's view, particularly in the senior management of the FCRCs. Stagnation in ideas is the more serious consequence of such a trend.

# VII. RECOMMENDATIONS

## VII. RECOMMENDATIONS

1. The Federal Contract Research Centers, supporting Defense Department agencies, are so valuable a resource, because of their perspective, the quality of their work, and the responsiveness they can exhibit because of their special relationship to their sponsorship, that they should be retained and protected in essentially their present roles. *This recommendation is meant to be read as a strong endorsement of current Defense policy in utilization of the FCRCs.*

2. Alternatives to FCRC utilization all require transitional preparations which will be sufficiently extensive that, in the event Defense decides on one or more such alternatives, a phased changeover must be programmed over a period of from 3 to 5 years. Our rank ordering of the preferred alternatives follows.

   a. Removal of line-item support for the current FCRC family should being with the two large SE/TD performers: Aerospace Corporation and MITRE. This would put them on a basis comparable with Johns Hopkins University's Applied Physics Laboratory. To compensate these performers, all competition and growth restrictions should be removed, and ASPR guidelines with respect to fee and marketing should be modified accordingly. Whatever special relationships these three operators can negotiate with their respective present Program Manager-sponsors should be allowed on a contract-by-contract basis. Let them compete with the industry and in-house performers for their future after suitable phase-out or novation of current contracts. Level-of-effort contracts should be negotiated with Lincoln and Penn State on whatever terms they can obtain from each of their current sponsors. This will work a particular hardship on these two organizations, since they traditionally have had single-contract coverage and they do not have staff for the administrative functions attendant to multiple-contract operation. Lincoln at least will have trouble surviving this transient because of its multiple-sponsor characteristic. The study and analysis performers, RAND, IDA, ANSER and CNA, will be best replaced by organic performers combining civil service and military personnel, and government lead time in establishing billets and staffing them should govern the time phasing. Continuing the current contract form would be the most appropriate interim methodology for assuring support to their current sponsorship. Negotiation between Defense and the Services on exact schedules is required.

   b. A phase-out of all FCRC performers by fiat through direction to the individual service secretaries with a set time scale to be complied with and complete discretion as to the form of successor performers would be a second choice. Our advice would be to put this date 5 years from your decision time.

c. Individual programs or, better, program areas which Defense deems mature could be designated as inappropriate for an FCRC involvement and a piecemeal reduction in required FCRC support would be a consequence. Industrial performers are competent and eager to acquire the involvement now enjoyed by the FCRCs. A reassessment, perhaps 3 years after this method is employed to reduce FCRC activity, could give Defense management a check on effectiveness.

d. Government corporations could be created to match each FCRC.

e. Civil service agencies could be established in all areas.

f. Technical military personnel could be organized to perform the missions.

The major elements of the alternative solutions proposed above are discussed in detail in the Terhune Report to which we subscribe in general.

3. Since we do not recommend any of the alternatives listed above, we make the following recommendations with respect to the governance and operation of the FCRCs.

   a. Since Lincoln, PSU/Applied Research Laboratory, and JHU/Applied Physics Laboratory have a history of stability, a parent organization with quality and an expressed intent to regulate size, and a reasonably unique orientation, we feel the best management posture Defense can adopt would be as close to "hands off" operation as is consistent with maintaining focus and meeting the accountability requirements of contract administration.

   b. The study and analysis FCRCs are more needful of level-of-effort line-item support.

      i. RAND needs to apply itself to its non-Air Force DoD tasks in a mode more consistent with its Project RAND activity. This will require closer involvement with Defense collectively and we feel a steering committee with Defense Department chairmanship is at least an initial step one might contemplate.

      ii. IDA needs a tougher problem orientation with a closer involvement on major and controversial Defense/JCS issues. WSEG gives indication that it understands the recent lessened impact of IDA on decision making and the correct words are used about reorientation. Keep an eye on that issue.

iii. ANSER and CNA appear to be fast-reaction, technically oriented agents of the Air Force and Navy staffs. CNA exhibits much more independence than does ANSER and that pattern may be useful to keep in mind. The deeper involvement between CNA and the fleet through the OR program afloat may be worthy of emulation. Both need more rigorous quality-assessment processes for their output.

c. MITRE and Aerospace ought to be regulated to program funding with fixed percentages of program budgets, locally negotiated, applied to independent research and planning activity. A single contracting agent in the parent sponsor organization as now employed appears to us to give control where it belongs. The Aerospace and MITRE managements must be made to realize no guaranteed level of support can exist under this scheme and manpower fluctuations in phase with program life spans are an inevitable consequence.

d. All of the FCRCs are exhibiting stagnation trends which vary in degree. These trends should be modified. This attribute is particularly pronounced in the management tiers just below the principal executive officer. We strongly recommend that, by what ever means practical, some mobility be encouraged. Suggestions are noted here, but it must be pointed out that delicate negotiation with Boards of Directors or Trusteeship will be an inevitable consequence of these suggestions.

   i. Employment contracts for fixed time spans for any officer or employee above a given annual salary level – e.g. $45,000.

   ii. Transfer of FCRC senior management staff between centers for fixed terms (Lincoln/MITRE; RAND/Aerospace and between any of the Washington-area FCRCs on a trial basis could be attempted with little personal inconvenience for the individuals so chosen).

   iii. Fixed-term assignments for some percentage of all new hires may be another strategem for turning over a higher volume of the technical staffs.

   iv. Some arrangement with industry to permit internships for FCRC personnel in development- and production-oriented organizations may produce some part of the desired cross fertilization.

e. The currently used modified ASPR guidelines for fee negotiation should be retained as long as a mutually benefitting special relationship is retained.

f. After much discussion and some internal disagreement on scale, the committee consensus is that current DoD practice on diversification should remain as it is presently understood.

g. Staff salaries at FCRCs should be allowed to stay as they are now — market determined. Senior level salary restrictions should be removed at the rate at which the Federal Government has relaxed its senior-level compensation restrictions.

h. While our observation is that compensation rates paid technical staff personnel in the FCRCs are reasonable, we are unsure about determinations made with respect to how many people belong in a given category. A standard for negotiation should be developed to guide the responsible government agents in this respect. In all other cost-related areas, we find no significant differences between the FCRCs and the industry.

# VIII. ADDENDA

(To be answered by each individual FCRC)

1. Does your FCRC still possess a type of level of capability outside or beyond that available in the in-house laboratories or in private industry?

2. Do its assigned tasks demand such capability, or could they be done in-house or in industry?

3. Are there extra costs involved in using the FCRC over that of doing the task elsewhere; if so, are they justified by the nature of, or quality of, the work?

4. What are the trends for the FCRC with respect to:

   a. level of staff competence?
   b. areas of staff competence?
   c. attention of management to DoD needs?
   d. levels of DoD/non-DoD activities?

5. What would be the likely consequences of ending "line item" support in an orderly way?

6. What would be the likely consequences to DoD and the FCRC of a 5- to 10-year phased ending of the FCRCs "special status"?

7. Does the FCRC possess unfair advantages with respect to (a) not-for-profits or (b) for-profits as a result of:

   a. its privileged position with respect to its DoD sponsor?
   b. the size of its fee?
   c. its tax-free status?

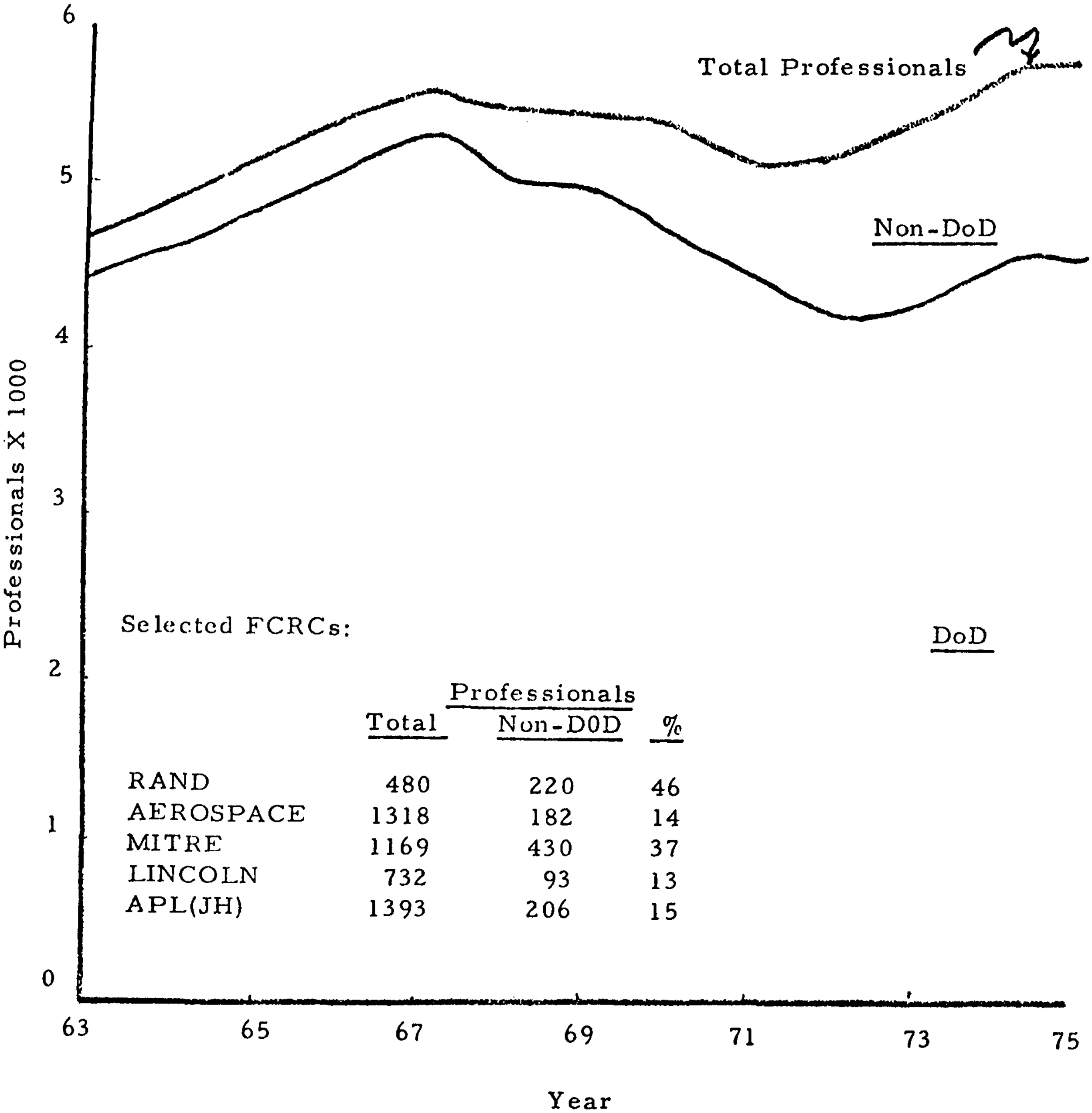
   when these are balanced against the restrictions peculiar to FCRCs, including:

   a. ceiling control?
   b. exclusions on work undertaken?
   c. restriction on competition?

8. Are controls on the size of the FCRC and the tasks it accepts, both DoD and non-DoD, appropriate? Is there a better way?

Addendum A

## FCRC DIVERSIFICATION
By Professional Staff




Selected FCRCs:

| | Total | Professionals Non-DOD | % |
|---|---|---|---|
| RAND | 480 | 220 | 46 |
| AEROSPACE | 1318 | 182 | 14 |
| MITRE | 1169 | 430 | 37 |
| LINCOLN | 732 | 93 | 13 |
| APL(JH) | 1393 | 206 | 15 |

Addendum B

TURNOVER RATES

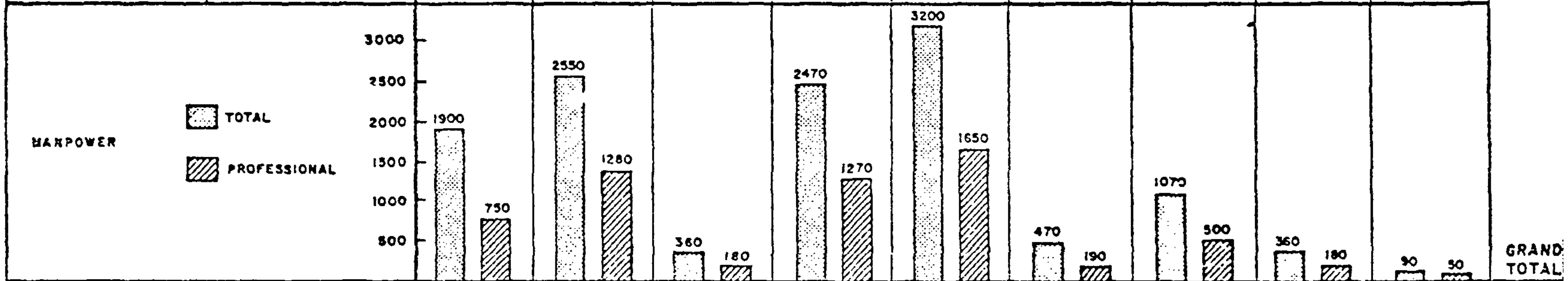
| FCRC | Rate % | Source | Remarks |
|---|---|---|---|
| IDA | 50 | Notes/Chart | |
| CNA | 13-17 | Notes | |
| APL (JHU) | 4-6 | Telephone | Over 5-year period |
| ANSER | 16 | Charts | |
| MITRE | 10 | Notes | |
| LINCOLN | 8 | Notes | |
| RAND | 15 | Charts | Over 5-year period |
| AEROSPACE | 9 | Notes | |
| PENN STATE | 10 | Charts | Over 5-year period; very low last year |

Addendum C

## COMPARISON OF FCRC's

ECR JUNE 75

| NAME OF FCRC & YEAR OF FORMATION | | LINCOLN LAB (1951) | APPL. PHYS. LAB (1942) | APPL. RES. LAB (1945) | MITRE (1958) | AEROSPACE (1960) | IDA (1956) | RAND (1948) | CNA (1962) | ANSER (1958) |
|---|---|---|---|---|---|---|---|---|---|---|
| UNIVERSITY AFFILIATION | | MIT | JOHNS HOPKINS | PENN STATE | | | | | UNIVERSITY OF ROCHESTER | |
| TYPE OF ORGANIZATION | | LABORATORY | | | SYSTEMS ENGINEERING & TECHNICAL DIRECTION (SE&TD) | | STUDIES & ANALYSIS (S&A) | | | |
| PRINCIPAL SPONSOR | OFFICE OF SECRETARY OF DEFENSE | | | | | | ✓ | | | |
| | AIR FORCE | ✓ | | | ✓ | ✓ | | ✓ | | ✓ |
| | NAVY | | ✓ | ✓ | | | | | ✓ | |

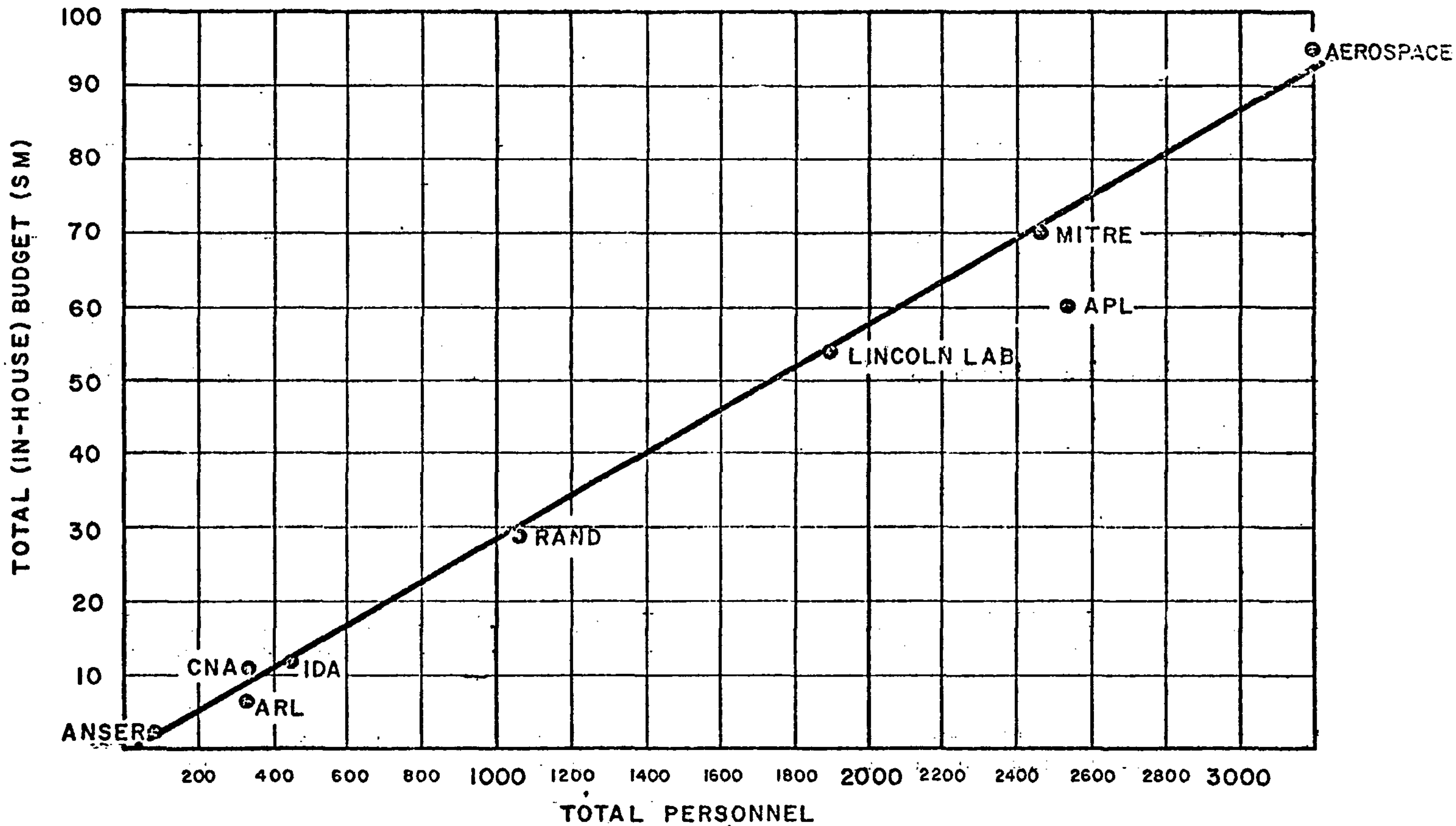



| | | | LINCOLN LAB | APPL. PHYS. LAB | APPL. RES. LAB | MITRE | AEROSPACE | IDA | RAND | CNA | ANSER | GRAND TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL (IN-HOUSE) BUDGET[1]/DOD CEILING | | $M | 53/48 | 60/50 | 7/7 | 70/45 | 95/80 | 12/11 | 29/16 | 11/10 | 2.5/2.4 | 340/26 |
| PART OF DOD BUDGET LINE FUNDED | | $M | 16 | — | — | 8 | 12 | — | 9 | 8 | 1.5 | |
| FEE | | % | — | 3.4 | 1.9 | 3.6 | 3.5 | 4.2 | 4.7 | —[2] | 3.7 | |
| % OF TOTAL BUDGET TO PRINCIPAL SPONSOR | | % | AF 51 | NAVY 72 | NAVY 100 | AF 52 | AF 77 | WSEG DARPA 90 | AF 31 ARPA 20 51 | NAVY 94 | AF 95 | |
| % OF TOTAL BUDGET TO OTHER DOD (EXCLUSIVE OF PRINCIPAL SPONSOR) | | % | ARMY 17 ARPA 19 NAVY 4 40 | ARMY 5 OTHER 5 10 | 0 | DCA 7 ARMY DARPA NAVY 14 | NAVY 3 ARMY 2 OTHER 2 7 | 0 | 6 | 0 | 0 | |
| DIVERSIFICATION (i.e. NON DOD) | | % | FAA HEW etc 9 | NASA DOT etc 18 | 0 | FAA, DEPT. JUST., NASA, DOT, EPA, NSF 34 | NASA 16 | FEDERAL AGENCIES ONLY 10 | HEW, NSF, DEPT HOUSING, FCC 43 | 6 | 5 | |
| PROFESSIONAL STAFF | PhD | % | 47 | 13 | 24 | 15 | 23 | 60 | 39 | 53 | 33 | |
| | OTHER ADVANCED DEGREES | % | 25 | 31 | 35 | 51 | 37 | 28 | 38 | 39 | 35 | |
| | AVERAGE AGE | YRS | 39 | 42 | 42 | 40 | 44 | 42 | 39 | 42 | 40 | |
| MAJOR TECHNICAL FIELDS | | | SPACE COMM REENTRY RADAR ATC ELECTRONIC SCI | SPACE NAVIG OPN'L EVAL AIR DEF MSL COMMAND & CONTROL | TORPEDOES & RELATED SCIENCES | C&C SYSTEMS COMM SYSTEMS SYSTEMS MGT | BALLISTIC MSL SYSTEMS SPACE SYSTEMS SPACE SCIENCE SPACE LAUNCH SYSTEM | STUDIES & ANALYSIS | STUDIES & ANALYSIS | STUDIES & ANALYSIS (NAVY) | STUDIES & ANALYSIS (AF HQ) | |

(1) TOTAL BUDGET DOES NOT INCLUDE "FLOW-THRU" PROCUREMENT

(2) 5% TO UNIVERSITY OF ROCHESTER FOR NAVY RELATED RESEARCH

## COMPARISON OF FCRC's



A Comparison of Educational Levels
in FCRCs and DoD Laboratories

Education-level data for personnel working for FCRCs and DoD Laboratories is as follows:

| | (1) Total Pers. | (2) Total Prof. | (3) % Prof. | (4) Adv Degree | (5) % Adv Degree | (6) No. Dr | (7) % Dr. |
|---|---|---|---|---|---|---|---|
| FCRCs | 12,275 | 6,116 | 50 | 3,794 | 62 | 1,517 | 25 |
| Army | 24,519 | 10,908 | 44 | 4,170 | 38 | 1,674 | 15 |
| Navy | 32,916 | 12,599 | 38 | 4,639 | 36 | 1,577 | 12 |
| AF | 7,907 | 4,389 | 55 | 2,297 | 52 | 735 | 16 |
| Total Labs. | 65,342 | 27,896 | 43 | 11,106 | 40 | 3,986 | 14 |

Notes:

*(1) Total Personnel means total employed. For FCRCs, this means for both DoD and non-DoD work.*

*(2) Percent Advanced Degrees and Percent Doctor Degrees is with respect to the total professionals.*

In a gross sense the professionals to total employees ratio comparison between DoD Laboratories and FCRCs is not dramatic (43% versus 50%). The Army and Navy have lower percentages (44% and 38%) however; this is not surprising because these organizations have full spectrum laboratories and more need for nonprofessionals (NWC – 69%; NUC – 64%, etc.). The Air Force, on the other hand, leans toward 6.1, 6.2 and 6.3 types of R&D and, therefore, the ratio is more similar to that of FCRCs.

If you look at the level of education within the professional force only (Columns 5 and 7), the FCRCs tend to have more people with advanced degrees. The advanced degrees to professionals level ratio in a total sense is 22% (62% to 40%) higher in the FCRCs than in the DoD Laboratories. The Air Force has a comparable ratio (55%), but their much smaller base does not greatly alter the overall DoD Laboratory percentage.

In terms of "Doctor" percentages, the FCRCs almost double (25% versus 14%) the Services. Even with respect to the Air Force, a significant difference exists between the number of doctors making up the professional force of the FCRCs (25%) as compared wtih the Air Force (16%).

In the comparison of FCRCs with DoD Laboratories, a question arises concerning the subject – are we comparing "apples and oranges"?. Two significant areas exist that could alter the data:

The Services have a number of medical facilities. The FCRCs have none.

The FCRCs have purely studies and analyses organizations. The Services have none.

In order to examine the data without these "differences", the medical data have been taken out of the DoD Laboratory figures and the studies and analyses data have been taken out of the FCRC figures.

| | (1) Total Pers. | (2) Total Prof. | (3) % Prof. | (4) Adv. Degree | (5) % Adv. Degree | (6) No. Drs. | (7) % Drs. |
|---|---|---|---|---|---|---|---|
| FCRCs | 10,342 | 5,130 | 50 | 3,009 | 57 | 1,007 | 21 |
| Army | 21,509 | 9,676 | 45 | 3,474 | 36 | 1,136 | 11 |
| Navy | 31,607 | 12,192 | 39 | 4,361 | 36 | 1,411 | 12 |
| AF | 7,611 | 4,226 | 56 | 2,186 | 52 | 677 | 16 |
| Total Labs | 60,727 | 26,094 | 42 | 10,021 | 38 | 3,224 | 12 |

The data show that there is no major change in the relative positions of FCRCs versus DoD Laboratories:

The percentage of professionals is essentially the same

The percentage of advance degrees is slightly lower both in FCRCs and DoD Laboratories but the relative positions are not altered

The Doctors ratio is still essentially two to one, with the FCRCs having the larger percentage of doctors in their professional force.

CONCLUSIONS

FCRCs and DoD Laboratories have a similar mix with regard to professionals as a proportion of total employment.

The FCRCs have a 22% greater population of advanced degrees than that of the DoD Laboratories.

The FCRCs "Doctor" population within their professional staffs is about twice that of the DoD Laboratories' professional staff.

# EVALUATION OF STRATEGIC FORCE-RELATED TECHNOLOGIES

Prepared For:

Defense Science Board
Summer Study on
The Strategic Nuclear Balance

<u>Strategic Technology Balance Panel</u>

July 1978

CONTENTS

EVALUATION OF STRATEGIC FORCE-RELATED TECHNOLOGIES

## 1.0 INTRODUCTION

Maintaining a strategic balance with the Soviet Union requires the continuous evaluation of many factors relating to the overall strengths and weaknesses of the two nations. A principal consideration in determining the relative balance includes the military factors, particularly those military capabilities related to the equivalence of each nation's strategic nuclear forces. This paper proposes a methodology for evaluating the current U.S. strategic force structure in terms of the additional future capability that could be achieved through the application of advanced technology initiatives.

### 1.1 The Approach

The approach to this evaluation problem involves the formulation of a hierarchical structure which reproduces the essential elements of the strategic force equation. Through a process of decomposition, the structure is designed to provide a logical relationship between U.S. national strategic objectives and the components of the strategic forces that could be improved by the selective allocation of technological resources.

The hierarchical structure, which is diagrammed in Figure 1-1, identifies three national strategic military objectives along the upper level of the model. These are:

- to ensure that the U.S. deterrent capability in terms of a secure retaliatory capability is clearly perceived by the Soviet Union;

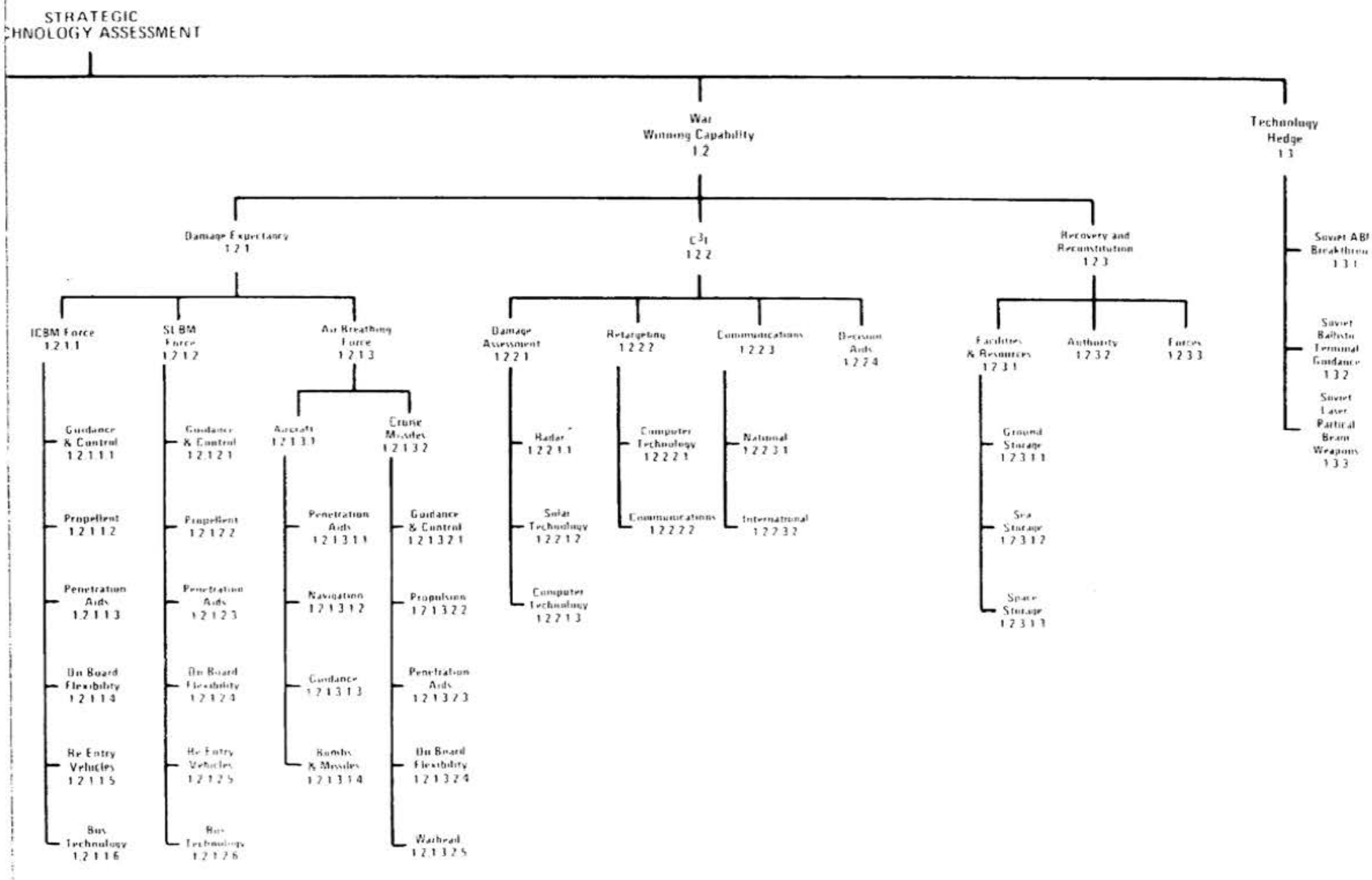



Figure 1-1

STRATEGIC TECHNOLOGY ASSESSMENT

- if deterrence should fail, to ensure that U.S. strategic forces possess a war-winning capability; and

- to avoid technological surprise.

The intermediate levels of the structure (Figure 1-1) provide a further decomposition of the problem into more easily understood subelements of the problem. For example, Perceived Deterrence consists of U.S. actions to enhance the survivability of U.S. retaliatory forces through hardening, dispersal, and concealment measures; to increase force readiness through improved tactical warning measures; and to reduce attrition through improved defensive measures. The lower levels of the structure define specific system elements which, if improved by the application of advanced technology, would contribute up through the model, thereby impacting on the achievement of one of the strategic military objectives.

This type of modeling, by which it is possible to evaluate the impact of alternative technology investment strategies that have values on a number of different attributes, is referred to as multi-attribute utility assessment. A technical discussion of multi-attribute utility analysis is contained in Appendix A. The application of multi-attribute utility assessment to this problem is discussed in the paragraphs that follow.

## 1.2 Scaling Technologies as an Input to the Model

The purpose of the evaluation structure outlined in Figure 1-1 is to quantify the value of alternative resource allocations by deriving a summary measure of value across all strategic force considerations for each technology initiative. The initiatives to be evaluated for their potential contribution to the strategic force structure (and which are described in detail in Appendix B) are: data processors, surveillance, land combat, life sciences, naval combat, strategic technologies, space systems, materials/ physical sciences, and energy weapons applications.

The quantification process consists of two steps--the assignment of subjective values to represent the potential contribution of each technology to an improvement in a component of our strategic forces (represented by the endpoints in Figure 1-1) and the assignment of weights to represent the relative importance of achieving the maximum improvement in a particular component. The model is installed on a computer which combines the scores and weights to yield a weighted average value for each technological application.

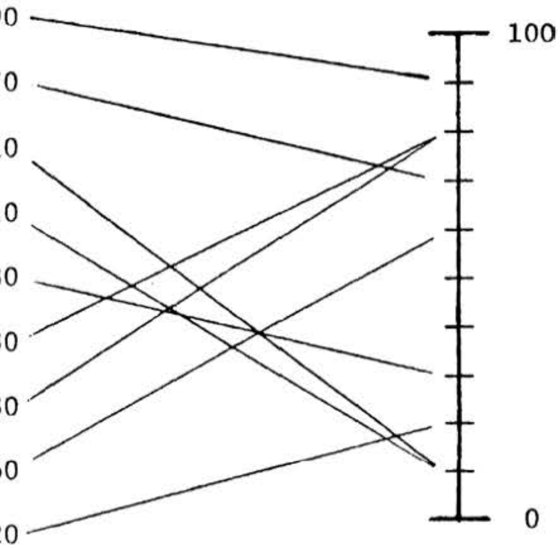
The assignment of values as an input to the model is illustrated in Figure 1-2. The abbreviated rationale for the values which appear at the bottom of Figure 1-2 may also be entered into the computer with the values. Work sheets, illustrated in Figure 1-3, will be provided each participant as a means of recording scores. Illustrative considerations which should be used for reference when assigning these scores are given in Appendix C for each endpoint.

## 1.3 Assessment of Importance Weights

The importance weights, as noted above, indicate the importance of achieving the maximum amount of improvement in each element of the strategic force. (A description of each element is contained in Appendix C.) For example, Figure 1-4 displays a part of the structure with illustrative sets of importance weights. It is important to note the weights are "swing weights" and represent the improvement in going from today's status to the most improved condition attainable given reasonable estimates of what is technically achievable

| Technologies | Risk | Values |
|---|---|---|
| 1. Data Processors | M | 90 |
| 2. Surveillance | L | 70 |
| 3. Land Combat | | 10 |
| 4. Life Sciences | | 10 |
| 5. Naval Combat | | 30 |
| 6. Strategic Technologies | | 80 |
| 7. Space Systems | | 80 |
| 8. Materials/Physical Sciences | | 60 |
| 9. Energy Weapons Application | H | 20 |

Strategic Component; Force Survivability, Mobile/Concealed Land-Based ICBM (Value Scale)




Abbreviated Rationale for Values

| | | |
|---|---|---|
| 1. | 90 | Improved missile G&C units; retarget for each new launch point. |
| 2. | 70 | Improved alert time for gyro warm-up; characterize attack for retargeting. |
| 3. | 10 | Some transfer from improved logistics/maintenance techniques. |
| 4. | 10 | Protection of ops/maintenance personnel, equipment from radiation, heat, blast. |
| 5. | 30 | Transfer of miniaturization techniques, approaches; remote control technology. |
| 6. | 80 | Improved guidance systems; improved penetration capability. |
| 7. | 80 | Improved warning and alert times; improved $C^3$ during execution phase. |
| 8. | 60 | Improved shielding materials; improved micro-circuitry. |
| 9. | 20 | Improved system area defense. |

Figure 1-2. ASSIGNMENT OF VALUES

## EVALUATOR'S SCORING SHEET

Node Number ____________; Evaluators Name ______________________________ Date: ______________

| TECHNOLOGY CODE Rank ① Technologies | SCORE ② TECHNOLOGIES | MAXIMUM SCORE: Where 100 ≡ Ideal | CODE | ③ DESCRIBE RATIONALE (Enter Technology Code for Each) | ASSESS RISK: ④ H,M,L |
|---|---|---|---|---|---|
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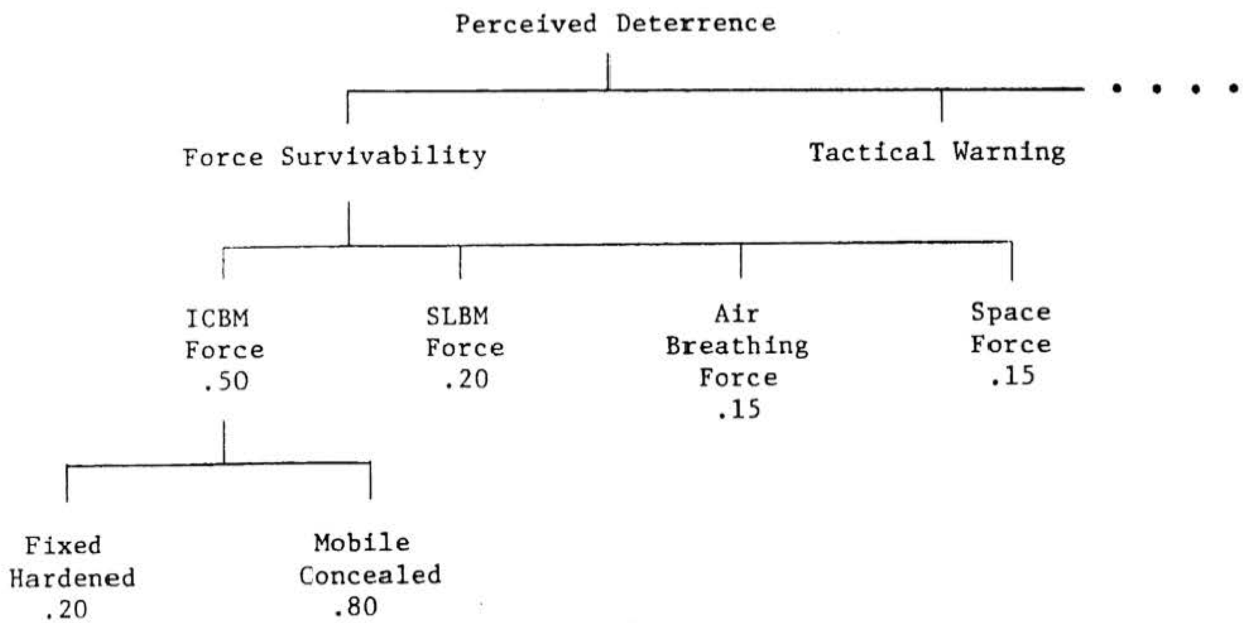
TECHNOLOGY CODE: Data Processors (DP), Surveillance (S), Land Combat (LC), Life Sciences (LS), Naval Combat (NS), Strategic Technology (ST), Space Systems (SS), Materials/Physical Sciences (MP), Energy Weapons (EW)

Figure 1-3




1. Rationale for Upper-Level Weights (.50, .20, .15, .15)

   a. ICBM has the appearance of being more vulnerable than SLBM force. By making the ICBM force mobile, the survivability would be greatly enhanced. New Tridents (SLBM force) appear to be relatively secure; potential improvement area more limited for Trident than Minuteman.

   b. The air breathing (cruise missile) force and space force are currently receiving benefits of new technology. Only small incremental improvements realistically attainable.

2. Rationale for Lower-Level Weights (.20, .80)

   a. Further hardening of ICBM silos would not yield significant, long-term survivability enhancements, whereas mobility and concealment would decrease vulnerabilities even in the face of further Soviet CEP improvements.

Figure 1-4. ASSIGNMENT OF WEIGHTS

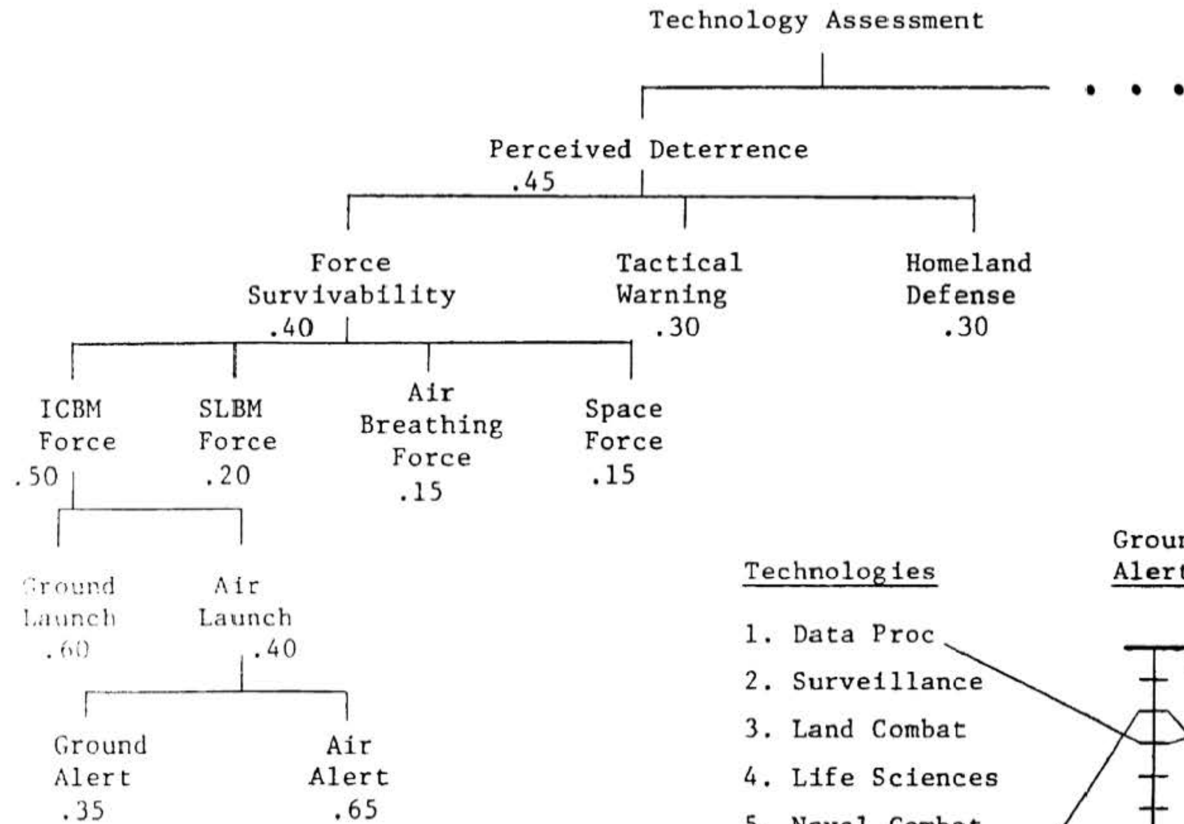
during the next ten years. One interpretation of the weights assigned in the example (Figure 1-4) is that it would be four times as effective in terms of the Soviets' perception of the U.S. second strike capability to develop a mobile system than to further harden existing silos.

## 1.4 Combining Scores and Weights During the Evaluation Process

The scores and weights that are assessed as inputs for the model are combined to yield a summary measure of value for each of the technologies. An example of this combination process is outlined in Figure 1-5. In the illustration, the importance weights in each single thread, beginning with an input node at the bottom of the model and proceeding up through the upper levels, are combined to yield cumulative weights. The cumulative weights represent the relative importance of a particular node to all other nodes in the model. The cumulative weight is combined with the values to yield a weighted value for each input node. These weighted values are summed and displayed as an output at the top of the model and represent the value of the technologies.

## 1.5 Output of the Evaluation Model

When the importance weights have been assigned to the structure and all of the values representing the potential contribution of the technologies to components of the strategic forces have been added, a number of different outputs are obtainable from the model. The user can rank order the technologies in accordance with their potential contribution to an improved strategic force posture. He can examine the contribution of each technology to a specific national objective or to a major element of the intercontinental delivery system. The user can also perform sensitivity analysis by varying the importance of objectives or force

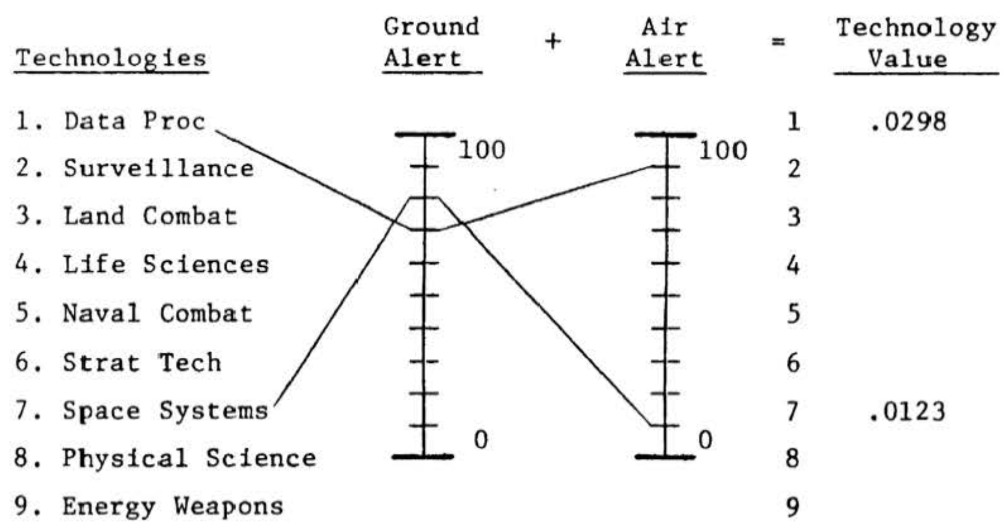



Ground Alert CUM WT:

.35 x .40 x .50 x .40 x .45 = .0126 (CW)

Air Alert CUM WT:

.65 x .40 x .50 x .40 x .45 = .0234 (CW)




1. (.7 x .0126) + (.9 x .0234) = .0298

2. (.8 x .0126) + (.1 x .0234) = .0123

Figure 1-5. COMBINING WEIGHTS AND VALUES components to determine the impact of the variations on different technological resource allocations.

APPENDIX A

# USING MULTI-ATTRIBUTE UTILITY THEORY FOR EVALUATION OF COMPLEX ALTERNATIVES

A methodology currently in use in many option selection and evaluation studies is decision analysis, a methodology for the quantification of the value of alternative decision options in the face of uncertainty. A specific sub-area of decision analysis, known as multiple objective decision making or multi-attribute utility assessment (MAUA), is employed in decision analytic studies for quantification of the value of very complex alternatives that have values on a large number of attributes. Because this methodology addresses the value of complex options in highly uncertain environments, it is particularly suited to the evaluation of the need for systems or programs to be supported in an uncertain, highly complex, future.

A MAUA model is hierarchical in nature starting with the specified top-level factor for which an overall score is desired. This factor is successively decomposed into sub-factors in descending levels of the hierarchy such that each successive level is more specific than the preceding. At the lowest level of the hierarchy are sub-factors for which scores will be directly assessed. For a system, these are the more easily understood operational or technical characteristics of the objects under evaluation. For a program, these may be specified attributes of potential program performance.

Also included in the hierarchy at intermediate levels and appropriately interrelated are all relevant "conditioning variables." Such variables are those upon which the value of some sub-factor of the object under evaluation could be dependent. Examples for a system evaluation are scenarios representing different conditions of system deployment, different environments, relevant future events, different platforms upon which a system would perform, and the like. Examples for a program could also be different scenarios in which the program would operate, other programs that could be implemented that would directly or indirectly impact the program under consideration, different government policies, and the like. Assessments of system performances, for example, and the associated worth of such performances will be dependent on the identity of these conditioning variables and assessed separately for each feasible combination of them. All this is to say that conditioning variables define the contexts in which the system or program will operate or in which the object will be evaluated.

The high level factors of an MAUA model are factors related, for example, to operational requirements for the system, program goals, etc. The desire is to model not how the system, program, or object is configured but to validly capture the needs that the system, program, or object will satisfy in terms of information needs, environments, threats, and the like.

Once a hierarchical structure has been created that decomposes high level factors into sub-factors that correspond to observable system or program elements, several steps must be accomplished. The first is determination of the combination rules by which the elements of sub-factors combine to determine the value of those sub-factors. Such rules take on different forms depending on the value dependencies among elements. Independent elements can be combined additively, whereas more complex combination rules, often multiplicative in nature, must be utilized to incorporate value-wise dependencies. Similarly, combination rules must be established for sub-factors at all levels of the hierarchy. The combination rules, once properly established, provide for aggregation of values up through the hierarchy.

Given the structured model with appropriate combination rules, several steps are necessary. First, plausible ranges must be defined. Such ranges must encompass all system or object element variation likely to be observed. Depending on the nature of the evaluation, this could, for example, be intra- or inter-system performance variance or potential variation in program performance levels. These ranges are necessary to allow meaningful judgments about the values of different levels of system or program elements.

The final two steps in model creation depend on the nature of the structure and the complexity of inter-element dependencies. A value function is assessed over the range of each system or program element assuming nominal fixed levels of all other elements. Such a function attempts to display how overall system or program value varies as a function of variation in that element. The more complex the inter-element dependencies, the more difficult are these functions to assess.

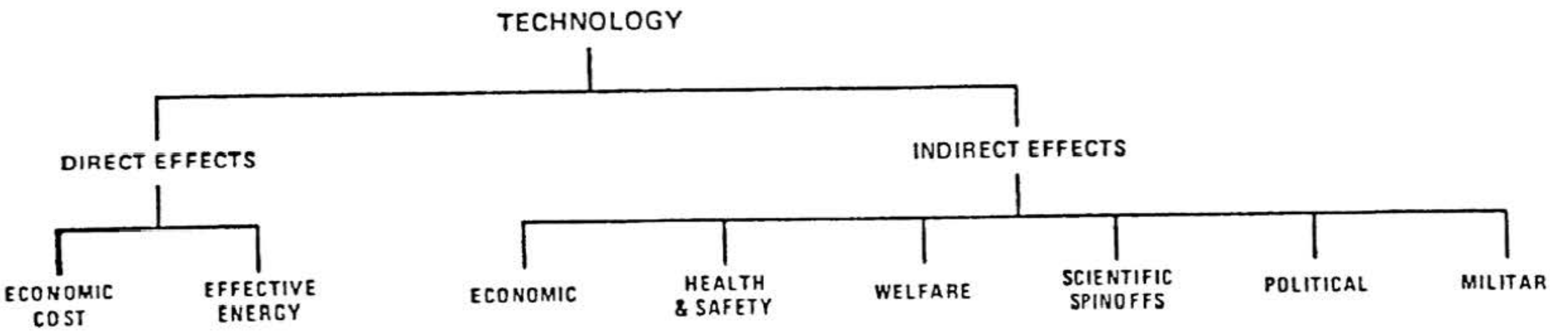
For well defined systems such as those involved in military procurements, the elements at the bottom level of the hierarchy may be physical performance characteristics such as speed, weight, probability of achieving a specific performance level, and the like. Such characteristics facilitate the assessment of a utility function that directly relates the levels of performance to overall system value. For other aspects of a system or object, the elements may be more subjective in nature. Examples are quality of management, past performance on contracts, quality of personnel, type of work, nature of population served by a program, and the like. Such elements are scaled using an arbitrary range, say, zero to 100, where different points along the zero to 100 continuum are defined using known or hypothetical object descriptions. Objects under evaluation are then scaled by comparison with established anchor points on the zero to 100 scale.

Also assessed for each factor are the relative importances of all sub-factors that contribute to that factor. Thus, if a lower level sub-factor of the model consists of three system or program elements that combine in a specific manner to determine the value of the sub-factor, assessments are made of the potential relative contribution to the sub-factor, of swinging each of the elements through its entire range as earlier defined. The nature of procedures for assessing such relative importance weights depend on the complexity of inter-element and inter-factor dependencies. Assessment of these weights is the final step in model construction.

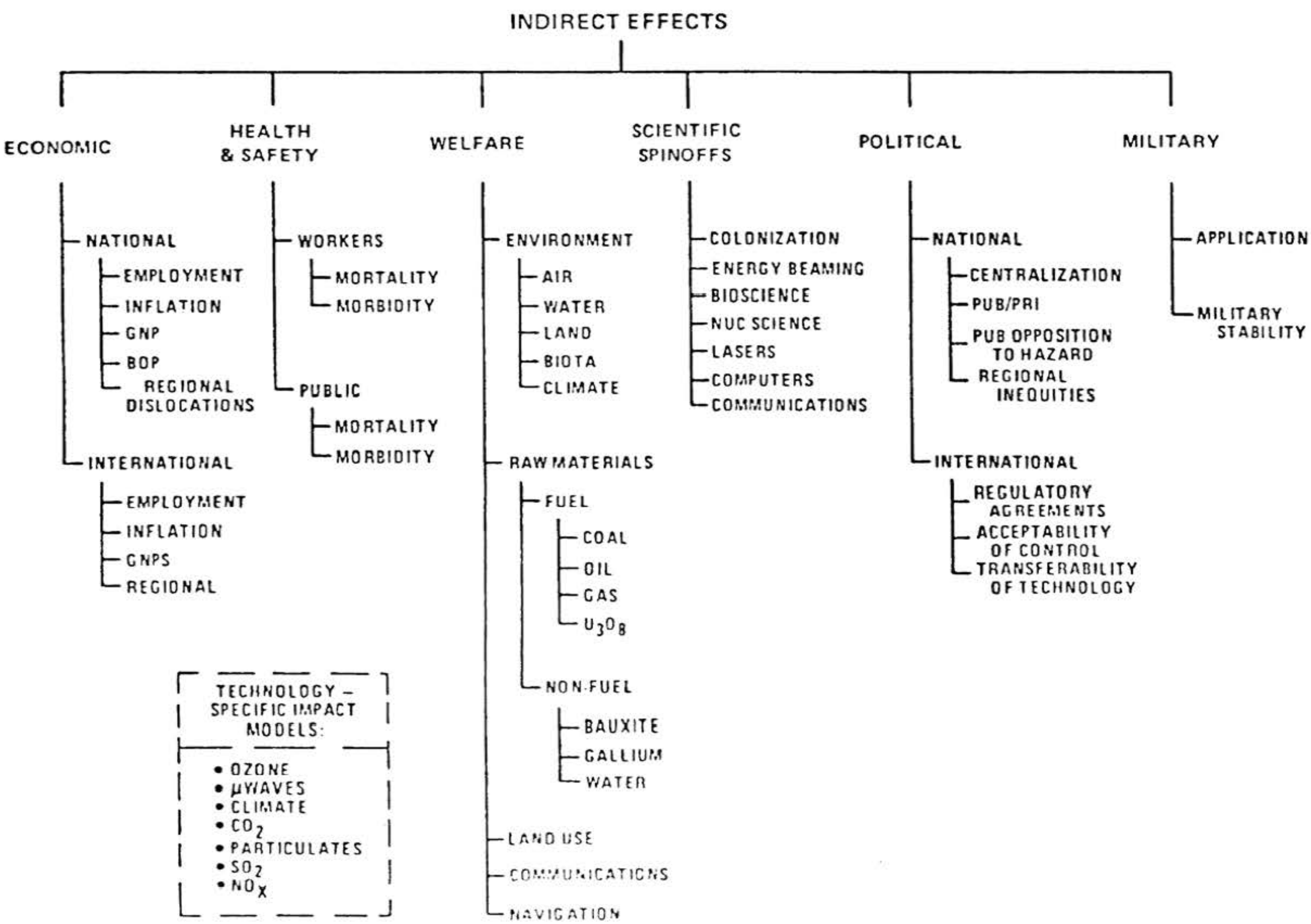
In order to conduct an evaluation, the model is implemented on an interactive computer using graphic displays. Because the model structure is, by its nature, traceable and visible, it can be quickly examined level by level, factor by factor, for purposes of understanding observed outputs. Importance weights, value functions, and combination rules can be examined for validity. The reasons for value judgments used in the model can be stored in the computer and are accessible by the analyst. Disagreements about weights or other inputs can be quickly resolved by conducting sensitivity analyses, changing whatever inputs are in question.

The methodology described has been used for evaluation of the potential value of numerous complex systems, including radars, air systems, missile defense systems, force mixes, and the like. With modifications, the approach has also been used to develop measures of force readiness, of water quality, of geothermal plant site suitability, of progress toward management goals, of need for air system modifications, and of cost/benefit trade-offs among budget categories. Such diverse applications emphasize the value of the approach as a general decision-making tool.

The following is an illustrative model for the evaluation of a satellite power station decision. A primary decomposition, as well as a further decomposition, of indirect effects are illustrated.




UTILITY MODEL: PRIMARY DECOMPOSITION




UTILITY MODEL: INDIRECT EFFECTS SUBMODEL

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Huber, G. P. "Multi-Attribute Utility Models: A Review of Field and Fieldlike Studies." Management Science, Vol. 20, (1974), pp. 1393-1402.

Keeney, Ralph L. and Howard Raiffa. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. New York: Wiley and Sons, Inc., 1976.

Keeney, Ralph L. The Art of Assessing Multi-Attribute Utility Functions Organizational Behavior and Human Performance. 19, 267-310, (1977).

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APPENDIX B

DEFINITIONS OF SIGNIFICANT TECHNOLOGIES

Data Processors - Includes micro-processor systems, distributed systems and multi-processor systems. The definition also encompasses artificial intelligence (AI) which has the potential of making computers more responsive to variability in inputs and unanticipated queries.

Emphasis is given to new technologies that will increase memories in capacity and radically reduce costs. The definition underscores expected micro-processor improvements and reveals that "in a few years the number of circuits on a chip will increase by more than ten times . . . and by 1990 entire systems will be integrated onto semiconductor wafers." One of the significant applications of the new technologies will be that of the direct sensor computer interface.

Surveillance - Includes expected advancements in radars that will permit classification of non-cooperative air targets; in electro-optical sensors for higher resolution satellite based surveillance; in DSP systems for determining ICBM/SLBM launch points, MIRV bus burns, aircraft take-offs and artillery firings; and in multi-technology ocean surveillance systems capable of detecting and classifying surface ships. The definition does not exclude other related technological improvements in IR sensors and OTH radars.

Land Combat - The definition focuses on European/NATO theatre conflict and includes insensitive explosives, RPVs, VTO aircraft, dynamic battlefield situation displays, target location systems, improved air defenses, all weather (low visibility) fire control systems, and vastly improved maintenance/logistics support systems for combat unit operations.

Illustrative applications included in the definition are aerodynamic improvements giving tactical aircraft improved penetration and weapons delivery capabilities; RPVs for target acquisition and defense suppression missions; radar surveillance for battlefield portrayal systems; and terminally guided munitions for attacks against tanks, artillery and vehicles.

Life Sciences - For this analysis, life sciences are concerned primarily with improving the effectiveness of ground force personnel to fight under conditions of stress induced by acoustical, acceleration, thermal, and toxic stresses. The projected environment will consist of intense, sustained around the clock combat in fluid, dispersed, and confusing battlefield circumstances.

The definition encompasses technology for improving U.S. offensive and defensive nuclear chemical and biological warfare capabilities. This implies improvements in protective materials, detection equipment, and training techniques.

Naval Combat - The definition focuses on surface ships and submarines. Candidate surface ship advancements include hydrofoils, air cushion vehicles (ACV), surface effect ships (SES), small waterplane area twin hulled (SWATH) ships, planing craft and wing-in-ground effect (WIG) vehicles. Their increased capabilities for the year 2000 include increased speed (up to 200 knots for WIG), additional operating flexibility, and improved sea keeping characteristics.

Technology advancements for submarine warfare encompasses noise reduction programs, ASW detection and localization techniques to include the use of magnetic anomaly detection, turbulent and thermal wake and electronic emissions along with acoustic devices.

The definition also includes the application of laminar flow and new propulsion approaches to the development of remotely controlled undersea vehicles and weapons, manned submersibles and remote sensors.

Strategic Technologies - The definition emphasizes the accuracy and vulnerability of ICBM, SLBM and aircraft cruise missile systems. More specifically, the definition is refined to include radio guidance for ballistic RVs, TERCOM type map-matching variations for cruise missiles, and improved penetration capabilities for manned aircraft and cruise missiles. The latter category consists of low altitude terrain profile flight systems, reduced radar cross sections, and increased speeds for cruise missiles. Hypersonic speed regimes are also possible in advanced SR-71 type aircraft.

Space Systems - Emphasis is on the increased real-time military support role of space systems to include surveillance, cueing, navigation, communications, command and control. This implies the application of advanced technology to the active and passive defense of U.S. space vehicles to physical and electronic attack. Passive measures include nuclear and laser hardening, encryption of command links, spare satellites, provision for maneuvering, tracking potentially hostile satellites and the deployment of silo based boosters. Potential future developments include space borne AWACS and BMEWS.

Materials/Physical Sciences - The broad definition includes electronic materials (silicon), magnetic bubble computer memories, optical fibers, optical integrated circuits, ceramic coated turbines, laser welding, and "in-field cloning" from polymers or steel of replacement parts.

Illustrative future applications are advances in geodetic instrumentation that could lead to increased missile accuracies and precision updating of navigation systems; new diphastic materials and fiber optic hydrophones for improved undersea surveillance; and low expansion, high stiffness optical materials for large space based optics.

Energy Weapons Applications - The definition centers on two applications; the charged particle beam and the electromagnetic gun. Both are described and the potential advantages and disadvantages of each are cited.

# APPENDIX C

## ILLUSTRATIVE CONSIDERATIONS FOR REFERENCE WHEN MAKING EVALUATIONS FOR THE INPUT REQUIRED AT MODEL'S ENDPOINTS

1.1.1.1.1.1 Fixed/Hardened - One approach to the problem of ensuring the security of the "second strike force" is to improve the survivability of the land-based ICBM force. One option includes silo hardening against blast effects and missile shielding and hardening against blast, thermal, and EMP effects. The capability of land-based systems to "ride out" an attack decreases with Soviet CEP/yield improvements.

1.1.1.1.1.2 Mobile (Concealed) - Another option for securing the retaliation force is to compound the attacker's targeting problem by concealing the land-based system in tunnels or playing "shell games" with the ICBM system by installing launchers and missiles on trucks or rail cars. The theory is to reduce significantly the amount of expected damage the attacker will achieve and to create doubt about the success of a pre-empt attack.

1.1.1.1.2.1 Aircraft (Ground Alert) - Another approach to ICBM basing options is to launch the missile from aircraft. The carrier aircraft can be maintained on ground alert in which case they are dispersed and capable of taking off and escaping the blast radius from incoming SLBM/ICBMs in several minutes. The aircraft, after take-off, fly to pre-determined launch points and launch their ICBMs when the "go code" is received by the aircraft launch crew.

1.1.1.1.2.2 Aircraft (Air Alert) - In another type of aircraft/ICBM option, the carrier aircraft are maintained on alert in the air rather than at dispersal airfields. This stresses advanced technology by requiring smaller missiles and more durable aircraft capable of loitering for extended periods of time.

1.1.1.2.1.1.1 Performance (SLBM Force) - This endpoint of the model refers principally to hull improvements such as laminar flow for increased (escape) speeds and increased strengths for less vulnerable operating depths.

1.1.1.2.1.1.2 $C^3$ (SLBM Force) - This refers to improved, less vulnerable communications, navigation and targeting systems. Requirement is to improve second strike reliability and flexibility under all conditions of nuclear war.

1.1.1.2.1.1.3 Noise/Wake (SLBM Force) - Refers to noise reduction, wake suppression, and other related programs to ensure survivability of U.S. sea-based ballistic missile forces.

1.1.1.2.1.2.1 Re-Entry VEhicle (SLBM Force) - Survivability can be enhanced by hardening the RVs to blast, debris, and EMP effects. Maneuvering RVs are also less vulnerable to many advanced ABM system concepts.

1.1.1.2.1.2.2 Range (SLBM Force) - Missile range extension programs can provide less vulnerable operating areas for the launch platform, thereby improving system survivability and increasing the number of arriving warheads.

1.1.1.2.1.2.3 Launch Depth (SLBM Force) - The launch platform can be made less vulnerable to damage from an attack during the launch phase if it does not have to launch its missiles from shallow depths.

1.1.1.2.2.1.1 Performance (Mini-Submersibles) - This endpoint refers to hull improvements, such as laminar flow for speed, new materials and welding for operating depths, and advanced, lightweight propulsion systems for range.

1.1.1.2.2.1.2 Noise/Wake (Mini-Submersibles) - Refers to noise reduction, wake suppression, and other techniques to reduce detection and improve survivability of small, widely dispersed undersea launch platforms.

1.1.1.2.2.1.3 $C^3$ (Mini-Submersibles) - This refers to improved, highly reliable communications, navigation, and targeting systems capable of reliable operations from widely dispersed locations during all conditions of nuclear warfare. Requirement is to improve second strike reliability and flexibility.

1.1.1.2.2.2.1 Re-Entry Vehicle (Mini-Submersibles) - Refers to small, high-yield warheads hardened against nuclear effects.

1.1.1.2.2.2.2 Range (Mini-Submersibles) - Missile range extension programs can provide less vulnerable operating areas for the launch platform, therefore improving system survivability.

1.1.1.2.2.2.3 Launch Depth (Mini-Submersibles) - The launch platform can be made less vulnerable to damage from an attack if it does not have to launch its missiles from shallow depths.

1.1.1.2.3 Remote Controlled Systems (SLBM Force) - Small, unmanned, remotely controlled systems to be used as defensive systems to protect larger (Trident type) launch platforms or as small, dispersed SLBM launch platforms. The "unmanned" design of the system should be optimized for deeper operating depths, longer patrol times, and larger payloads.

1.1.1.3.1.1.1 Fixed/Hardened (Cruise Missile Launch Sites) - Approaches to enhancing security of "second strike" cruise missile forces include rock granite adits and hardened silos at dispersed locations. The systems are hardened against blast, thermal, radiation, and other damage effects.

1.1.1.3.1.1.2 Mobile/Concealed (Cruise Missiles) - To reduce vulnerability to a nuclear attack, potential basing nodes include tunnels, trucks, railroad cars, and barges. The attacker's targeting problem is complicated by continuously relocating the launch platforms, creating false targets, concealment, or through some combination of the above approaches.

1.1.1.3.1.2.1 Submarine (Submarine-Based Cruise Missiles) - Survivability is increased by proliferating the long-range attack force by incorporating long-range cruise missile launch and fire control systems on all submarines regardless of ship's basic mission design.

1.1.1.3.1.2.2 Surface (Surface Ship-Based Cruise Missiles) - Option is to design long-range cruise missiles and launch platforms for incorporation with weapons/fire control systems on all surface ships regardless of basic mission.

1.1.1.3.1.3.1 Ground Alert (Aircraft-Based Cruise Missiles) - The approach consists of making the missile compatible with various types of long-range aircraft (bombers, aerial tankers, cargo, passenger) that can be dispersed and maintained on alert at small, non-military airfields. The objective is to proliferate the numbers of targets.

1.1.1.3.1.3.2 Air Alert (Aircraft-Based Cruise Missiles) - An approach is to ensure survivability by maintaining a portion of the cruise missile force continuously airborne.

1.1.1.3.2.1 Guidance (Cruise Missiles) - Guidance improvements are designed to decrease reaction times and increase maneuver and low altitude capability without degrading missile terminal accuracies. Additional improvements are to update positional data after launch and/or to insert target data while missile is in flight enroute to target.

1.1.1.3.2.2 Air Frame (Cruise Missile) - Weight reduction techniques are required to improve transportability, concealment, and vulnerability.

1.1.1.3.2.3 $C^3$ (Cruise Missile) - Hardened and survivable communications to improve response times and increase prelaunch survivability during operations from remote and dispersed locations under all conditions of general warfare.

1.1.1.4.1 Self-Detection Systems (Space-Based Strategic Weapon Systems) - Future technology initiatives should consider the requirement to base strategic attack systems in space. Given a general nuclear war scenario, vulnerable ground-based tactical alerting systems would not be capable of providing warning to space systems that were coming under attack. To increase the survivability of such systems, an on-board attack warning system would be required.

1.1.1.4.2 Self-Defense System (Space-Based Strategic Weapons Systems) - Given a general war scenario, such systems, to be dependable, should be capable of countering deception, jamming and physical attacks while the system is executed as part of the retaliation force.

1.1.2.1.1.1 Sensors (Tactical Warning) - One approach to ensuring a secure retaliatory force is to develop a capability to provide unequivocal warning of an attack. Given this capability, a retaliation strike could be launched before the attacking force has achieved significant damage against the U.S. retaliation force. The requirement is for spaceborne sensors of proven reliability under all conditions of weather and warfare.

1.1.2.1.1.2 Boosters (Tactical Warning) - The requirement is for reliable boosters to insert/replace sensors--booster criteria includes high reliability, quick reaction times, sustained periods of ground alert, and reduced vulnerability to war-induced damage effects.

1.1.2.1.1.3 Communications (Tactical Warning) - The requirement is for secure and reliable communications as part of the warning system.

1.1.2.1.2.1 Sensors (Tactical Warning) - The requirement is for airborne sensors (radar, OTH, IR, ESM, visual) and data processors of proven reliability which are capable of operating under all conditions of weather and warfare.

1.1.2.1.2.2 Airframe/Propulsion (Tactical Warning) - The requirement is for reliable aircraft capable of conducting reconnaissance during the early pre- and trans-attack periods of nuclear war. This requirement implies the development of aircraft and propulsion systems capable of continuous operations in an environment purposely created by the adversary to degrade the U.S. warning system.

1.1.2.1.2.3 Life Support (Tactical Warning) - The requirement is for reliable aircrew performance of duties related to the operation of platform, sensors, and processors for long time periods under the stresses and hazards of a nuclear attack. This implies crew protection against fatigue, blast, heat, and radiation.

1.1.2.1.3.1 Sensors (Tactical Warning) - The requirement is for ground-based sensors capable of continuous, reliable operations under all conditions of nuclear warfare.

1.1.2.1.3.2 Mobility (Tactical Warning) - The requirement is for highly mobile and survivable ground-based sensor platforms, sensors, data processors, and data transmission facilities.

1.1.2.2.1 Data Processing (Intelligence) - Data processing facilities and equipment designed to process multiple sensor inputs in real time. Compact systems designed to operate as integrated elements of on-board sensors to reduce complex, vulnerable data transmission links.

1.1.2.2.2 Analysis (Intelligence) - Reliable analytical systems capable of handling large amounts of multi-sensor data. Such systems, designed to reduce deception, false alarms, and enemy-induced malfunction rates, may interface directly with sensors and output displays.

1.1.2.2.3 Transmit and Display (Intelligence) - Includes portable systems designed to accompany the NCA and enhance confidence in attack warning system output during periods of tension.

1.1.2.2.4 Decision Aids (Intelligence) - Portable systems for providing the NCA optimal responses and force execution alternatives to wide ranges of nuclear threats.

1.1.3.1.1.1 Communications (Anti-Satellite; Homeland Defense) - The requirement is for a secure, reliable communications system for ensuring control and responsiveness of the U.S. anti-satellite system.

1.1.3.1.1.2 Guidance and Control (Anti-Satellite; Homeland Defense) - The requirement is for a highly flexible quick reaction system capable of resolving complex intercept and firing position problems during the target's zero orbit.

1.1.3.1.1.3 Fire Control System (Anti-Satellite) - The requirement is for a highly reliable system incorporating alternative kill mechanisms suitable for use during various levels of confrontation and conflict.

1.1.3.1.1.4 Propulsion System (Anti-Satellite) - The requirement is for long duration systems capable of complex velocity and planar changes as required for multiple identification and intercept maneuvers.

1.1.3.1.2.1 Communication (Air Vehicles; Homeland Defense) - The requirement is for secure, reliable communications with the airborne air defense force in order to ensure responsiveness and control during a nuclear attack against the U.S.

1.1.3.1.2.2 Performance (Air Vehicles; Homeland Defense) - The objective of the system is to engage the attacking force while enroute and at maximum distances from their U.S. targets. This objective implies advances in air frames, propulsion systems and sensors in order to extend the engagement area well beyond U.S. continental boundaries.

1.1.3.1.2.3 Fire Control System (Air Vehicles; Homeland Defense) - The requirement is for long range, accurate intercepts and kills of attacking aircraft. On-board friend or foe identification and enemy classification systems are implied for independent operations in remote areas.

1.1.3.1.3.1 Performance (ABMs; Homeland Defense) - The requirement is for long-range, high velocity systems capable of loitering in remote intercept areas.

1.1.3.1.3.2 Warhead (ABMs; Homeland Defense) - Alternative kill mechanism (nuclear, particle beams, lasers) capable of neutralizing multiple warhead (MIRC) attacks are a requirement.

1.1.3.1.3.3 Guidance/Fire Control (ABMs; Homeland Defense) - Guidance systems capable of performing on-board target/decoy classification and resolving the intercept problem after loitering in the intercept area are implied by the system requirement.

1.1.3.1.3.4 $C^3$ (ABMs; Homeland Defense) - Includes the requirement to manage the battle and conduct the intercept of incoming enemy missiles without degrading the fly out of the U.S. offensive air/space/ballistic missile/force.

1.1.3.2.1 Alerting Programs (Civil Defense) - This consists of warning systems of sufficient credibility to support a civilian shelter/evacuation program capable of reacting during periods of tension.

1.1.3.2.2 Survival Programs (Civil Defense) - This consists of equipment, shelter, medicine, and storage facilities to protect personnel and resources against the damage effects of a nuclear attack.

1.2.1.1.1 Guidance and Control (ICBM) - Improved accuracies which give the U.S. long-range delivery force the capability to neutralize hardened, dispersed, concealed, and mobile enemy targets. Such systems include hardening and maneuverability for increased survivability during the powered flight phase.

1.2.1.1.2 Propellants (ICBM) - Improved propellants which would give the attacking force increased range and provide for greater payloads by including additional penetration aids, and fuels for additional powered-bus flight maneuverability.

1.2.1.1.3 Penetration Aids (ICBM) - Advanced technology offers the potential for RV borne active mini-jammers, as well as decoys, balloons, chaff, and other forms of ECM.

1.2.1.1.4 On-Board Flexibility (ICBM) - Included are capabilities for in-flight target changes, launch-point position updating, and powered flight navigation refinements.

1.2.1.1.5 Re-Entry Vehicles (ICBM) - Included are packaging techniques for increasing nuclear yield, terminal homing and terrain matching systems and re-entry maneuvering capabilities as part of the RV system.

1.2.1.1.6 Bus Technology (ICBM) - Includes survivable bus technology with increased flight times and expanded footprints.

1.2.1.2.1 Guidance and Control (SLBM) - Improved accuracies which give the U.S. long-range delivery force the capability to neutralize hardened, dispersed, concealed, and mobile targets. Such systems include hardening and maneuverability for increased survivability during the powered flight phase.

1.2.1.2.2 Propellants (SLBM) - Improved propellants which would give the attacking force increased range and provide for greater payloads to include sophisticated penetration aids, and fuels for powered-bus maneuverability.

1.2.1.2.3 Penetration Aids (SLBM) - Advanced technology offers the potential for RV bornc mini-jammers as well as decoys, metal balloons, chaff, and other forms of ECM.

1.2.1.2.4 On-Board Flexibility (SLBM) - Included are capabilities for in-flight target changes and launch-point position updating, and powered flight navigation refinements.

1.2.1.2.5 Re-Entry Vehicles (SLBM) - Included are packaging techniques for increasing nuclear yield, terminal homing and terrain matching systems, and re-entry maneuvering capabilities as part of the RV system.

1.2.1.2.6 Bus Technology (SLBM) - Includes survivable bus technology with increased flight times and expanded footprints.

1.2.1.3.1.1 Penetration Aids (Air Breathing Force; Aircraft) - Consists of options for improving the penetration capability of the manned aircraft force. Possible approaches include improved air-to-surface radar homing (defense suppression) missiles, electronic countermeasures, bomber decoys, and radar absorption materials.

1.2.1.3.1.2 Navigation (Air Breathing Force; Aircraft) - Includes options to improve the reliability and accuracy of aircraft navigational and terrain contour systems.

1.2.1.3.1.3 Guidance (Air Breathing Force; Aircraft) - Options include terminally guided surface-to-air missiles, glide bombs, and penetrators launched from manned aircraft.

1.2.1.3.1.4 Performance (Air Breathing; Aircraft) - Options include improvements in airframes and propulsion systems leading to increased payloads, speeds, and range.

1.2.1.3.2.1 Guidance and Control (Cruise Missiles) - Improved navigational accuracies, terminal homing systems, terrain following capabilities, and self-protection against enemy-induced errors and malfunctions.

1.2.1.3.2.3 Penetration Aids (Cruise Missiles) - Improved penetration capabilities resulting from radar absorption techniques, electronic countermeasures, terrain following navigation, and radar avoidance maneuvers.

1.2.1.3.2.4 In-Flight Mission Flexibility (Cruise Missiles) - Optional improvements could include in-flight retargeting, recall and recovery capabilities, and a target validation mode of operation.

1.2.1.3.2.5 Warhead (Cruise Missile) - Optional enhancements include terminally guided, off-course dispensed, high-yield maneuverable warheads.

1.2.2.1.1 Radar (Damage Assessment; $C^3I$) - Improvements include all weather systems capable of identifying, classifying and assessing extent of damage to enemy and friendly forces and installations.

1.2.2.1.2 Solar Technology (Damage Assessment; $C^3I$) - Options include generation of solar energy to support systems required to perform damage assessment functions during periods of general nuclear war.

1.2.2.1.3 Computer Technology (Damage Assessment; $C^3I$) - Improved data storage for comparative analysis of pre- and post-strike damage assessment materials.

1.2.2.2.1 Computer Technology (Retargeting; $C^3I$) - Improved data storage, retrieval, and comparative analysis capabilities for matching residual strike resources, mission objectives, and target data base.

1.2.2.2.2 Communications (Retargeting; $C^3I$) - Reliable communications resources for transmitting target data to withheld/residual/dispersed attack forces.

1.2.2.3.1 National (Communications; $C^3I$) - Communications required to support the recovery/reconstitution phase of a general nuclear war.

1.2.2.3.2 International (Communications; $C^3I$) - Communications required for the termination/negotiation phase of a general, nuclear war.

1.2.2.4 Decision Aids ($C^3I$) - Executive aids to support the NCA (and alternates) during the trans/post phases of a general nuclear war.

1.2.3.1.1 Ground Storage (Facilities and Resources; Recovery and Reconstitution) - Requirement includes underground facilities for storing materials, equipment, munitions, and delivery vehicles associated with recovery and reconstitution.

1.2.3.1.2 Sea Storage (Facilities and Resources; Recovery and Reconstitution) - Requirement includes undersea facilities for storing materials, equipment, munitions, and delivery systems required for recovery and reconstitution.

1.2.3.1.3 Space Storage (Facilities and Resources; Recovery and Reconstitution) - Requirement includes spaceborne capability for storing materials, equipment, munitions, and delivery systems required for recovery and reconstitution.

1.2.3.2 Authority (Recovery and Reconstitution) - Options for maintaining continuity of national authority during all phases of nuclear warfare.

1.2.3.3 Forces (Recovery and Reconstitution) - Options for recovery and reconstitution of intercontinental nuclear delivery forces which have been executed, withheld, or dispersed.

1.3.1 Soviet ABM Breakthrough - Delivery system development options which can be implemented as a hedge against a significantly improved Soviet ABM system.

1.3.2 Soviet Ballistic Terminal Guidance Breakthrough - U.S. delivery system development options such as the creation of false aiming points.

1.3.3 Soviet Laser/Particle Beam Weapons Breakthrough - U.S. alternative countermeasure development program options.