POLICIES FOR MILITARY RESEARCH AND DEVELOPMENT

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The development of the atomic bomb during the Second World War signified a radical change in the importance of technology to national security. While the atomic bomb had only a small role to play in that war, recognition of the disaster which might have befallen us if our enemies had developed the bomb first, together with the beginning of thought on the implications of this new magnitude of firepower for future conflicts, raised technology to new heights of importance in the minds of government and military leaders. In possible future wars, they imagined that victory would go not to the nation with superiority in materiel, location, or military leadership but rather to nations possessing superior technology. Our subsequent confrontation with another nuclear power, the USSR, and our general preoccupation with large nuclear conflicts strengthened these feelings. Mirroring this concern was the rise of spending for military research and development from half a billion dollars in 1945 to more than six and one-half billion in 1966.

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The increase in importance of R&D activities has naturally led to attempts to develop efficient management practices for the conduct of R&D projects. Attempts were made difficult by a number of factors. Most important perhaps was the uniqueness of the R&D process. The civilian sectors of the economy had not had extensive experience with the purposeful conduct of R&D projects, particularly with the extremes of technological advance and development speed required by the military. Hence, the civilian sector provided few standards to guide the individuals responsible for establishing management policies for R&D. A more fundamental problem was the uniqueness of each R&D project. R&D is a creative process and thus difficult or impossible to generalize upon. Management procedures require such generalizations and hence the search for useful procedures has been a frustrating one. Finally, in setting up such procedures, there had been a tendency to seek efficiency in the individual project; to minimize the resources (or time) required to achieve a technical objective. Frequently the problem of achieving efficiency in the entire collection of R&D projects has been ignored. It is assumed that a collection of projects each of which is efficiently run will lead to the efficient achievement of total R&D objectives. As we shall see, this is not the case.

In spite of these difficulties, generalizations must be made, organizations and procedures established, and measures of effectiveness developed. Any group of organizations responsible for the magnitude of resources associated with R&D requires such guidance. In this chapter, we suggest a group of objectives for the military R&D programs, consider the structure of the present program, and indicate some of the problems found in meeting these objectives.

Objectives for the Military R&D Program

The military research and development program must provide the United States with the capability to produce weapons which are needed or may be needed to support the needs of National Security. At any point in time, the total R&D program encompasses efforts to improve existing forces, develop specific new equipment, and explore technologies which may be useful to future forces. More specifically, the objectives of the program can be viewed as:

1) To carry on the development of weapon systems required to meet the current military needs of our armed forces.
2) To expand the technological alternatives available to meet future needs of national security.
3) To provide (along with non-military research) a basis for understanding the implications of technological activities of our enemies.
4) To provide technological inputs to the planning process of the military services.

The Department of Defense Program Structure for R&D

The program which is designed to meet these objectives is divided into six categories. The categories are defined as:*

I. RESEARCH

Research includes all effort directed toward increased knowledge of natural phenomena and environment and toward solutions to problems in physical, behavioral, and social sciences having no clear, direct military application. By definition, "research" includes all basic research in addition to applied research directed toward expanding knowledge in various scientific areas. It does not include efforts to prove the feasibility of solutions of problems of immediate military importance or time-oriented investigations and developments.

II. EXPLORATORY DEVELOPMENT

This includes all efforts to resolve specific military problems short of major development projects. These efforts may vary from fundamental applied research to sophisticated "breadboard" hardware, study, gramming, and planning efforts. The dominant characteristic of this category of effort is that it is pointed toward specific

*These definitions follow closely those advanced by Robert S. McNamara in the 1964 Defense Appropriation Hearings, Hearings Before A Subcommittee of the Committee on Appropriations House of Representatives, 88th Congress, 1st Session, Part 1, Secretary of Defense, pp. 163-172.

military problem areas, with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters.

III. ADVANCED DEVELOPMENT

Advanced Development includes all projects that have moved into development of hardware for experimental or operational tests. Advanced Development is characterized by line-item projects, normally involving hardware designed for test or experimentation, as opposed to that designed and engineered for eventual service use.

IV. ENGINEERING DEVELOPMENT

Engineering Development includes development programs being engineered for service use but not yet approved for production or operation. This area is characterized by major line-item projects.

V. MANAGEMENT AND SUPPORT

This category includes research and development effort directed toward support of installations or operations required for general research and development use. It includes test ranges, military construction, maintenance of laboratories, operations, and maintenance of test aircraft and ships.

VI. OPERATIONAL SYSTEM DEVELOPMENT

This development includes research and development effort directed toward developing, engineering, and testing systems, support programs, vehicles, and weapons that have been approved for production and service use.

Several general observations can be made on the nature of these categories. Leaving aside the Management and Support area and treating Engineering and Operational Systems development as being nearly synonymous from the point of view of development objectives, the degree to which the work carried on in each category can be related to a specific system or system concept increases as we proceed from Category I to Category V. The size of the average project in each category similarly increases as we move from Category I to Category V. As a corollary to this, the degree of control and review exercised by higher headquarters or the Office of the Secretary of Defense (OSD) increases as we move from Research through to Systems Development.

In principal, the work done in Exploratory Development and Research provides the technological base for future systems as well as much of the information required by defense planners and intelligence experts. The Engineering and Operational systems development includes the efforts to meet immediate and near future equipment needs of the services. The Advanced Development activities represent a bridging of the gap between the technology efforts of exploratory development and the systems oriented efforts of Categories IV and V. Because of this responsibility, advanced development should be a key area in the present funding structure. It is the first place in the evolution of a system from its technological origin to its final form where the needs of the military are formally and realistically brought together with available and potential technological capabilities. The prototype hardware which is built is intended to be a concrete example of a military subsystem. The technologies demonstrated in this fashion are intended to be the "building blocks" used in the development of operational systems.

This procedure sounds quite neat and appropriate. Technological possibilities initially exposed in Research activities, are explored in Exploratory Development. As a result of such explorations, and as a result of looking forward to future military needs, specific parts of the technological base are chosen for exploitation in Advanced Development. The nearly developed subsystems coming out of Advanced Development are engineered into a weapons system in Engineering or Operational Systems Development programs. At each step the cost of the projects increase but presumably the quality of the information upon which the project decisions are made improves and the risk of technical error decreases. Unfortunately, the orderly process pictured here frequently fails to appear. An unanticipated military threat may arise and a system must be rushed into development without all of the technology being proven in advanced development. A program such as the X-15 with objectives appropriate to research or Exploratory Development may cost so much that it is placed in advanced development where control from higher headquarters can more easily be exercised. A program may enter into system development but an unanticipated technological problem forces basic experimental work to be undertaken in order to obtain a solution. While these type of events frequently take place, the principal behind the categories is sound and in any case represents the policy of the present DOD leadership.

Recognizing the varied characteristics of the programs which are called Advanced Developments, it is possible to define a series of subcategories of Advanced Development which are used by a number of people in order to clarify their thinking. These categories vary from person to person but generally are of the following sort:

1) Programs which represent the exploitation of promising technologies.

These programs are, in reality, exploratory in nature. However, they are judged to require a level of funding which is larger than the management methods used in exploratory development are designed to handle. For example, composite materials are judged to have great promise for obtaining required structural strength at reduced structural weight.* However, much basic work on the drawing of filaments, the placing of filaments in matrices, and the

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*M. L. Yaffee, Composite Materials Offer Vast Potential for Structure, Aviation Week, Vol 82, No 18, May 3, 1965, Page 38.

design of structures using composite materials must be accomplished. As a result, a large group of tasks has been brought together in the advanced development category where they can be managed collectively.

Exploratory Development is funded essentially at a level of effort. A decision to push one area very hard, as in the case of composite materials, requires a sharp increase in funding. If the program were left in Exploratory Development this would result in a distortion of the total Exploratory Development program since funds would have to be taken away from other portions of the program. Hence, we find the appearance of programs with objectives typical of Exploratory Development in the Advanced Development area.

2. Experimental Systems

Certain projects with Research or Exploratory Development aims require very expensive experimental hardware. Notable examples of such projects are the X-15 high speed test aircraft and the Manned Orbiting Laboratory (MOL). These projects require extensive management control alien to Research and Exploratory Development because their cost may reach several hundred million dollars.

3. Subsystem or component technical development

These activities provide the "building blocks" for future systems. Models of prototypes of components or subsystems are fabricated for experimental test.

It should be noted that there are those who feel that an orderly progression of technology through the Exploratory and Advanced Development stage to incorporation in systems is inappropriate and ineffective. It is argued that the efforts to develop technology require a focus such as that imposed by the need to produce a system. The requirement to build a system "pulls" technology along to meet this requirement. The result is a focusing of efforts upon a relatively few areas which are judged to provide the potential for significant improvements in military capabilities.

Supporters of this point of view argue that such an approach tends to reduce the amount of waste effort in the technology area by focusing on only the areas in which a consensus exists that significant breakthroughs are possible and required. Moreover, the schedules inherent in a systems development project provide discipline to the technologist thus preventing him from simply exploring a technical area because it is interesting.

Although there have been no public advocates of this position in recent years, supporters of such a position would probably advocate the elimination of most formal Advanced Development projects and some Exploratory Development projects in favor of defining systems which would require the use of the results of such projects. The actual work would be done as a part of the systems project.

Perhaps the last major project in which such an approach was followed was the B-70. The technological results of this program are very impressive,* and have found their way into many other military and civilian programs. Moreover, it is quite likely that without the impetus supplied by a systems effort with high performance requirements, many of these advances would not have been made. Their value would not have been perceived by the planners of the exploratory and Advanced Development efforts.

But this program also shows most of the shortcomings of such a means of advancing technology. The requirement for the aircraft was ultimately deemed to be invalid. The program, subject to many reorientations because of questions about the value of the system, slipped badly in time and escalated in cost. While a steady management effort would certainly have improved the time and cost performance, slippage and cost escalation would still have occurred. The result is the expenditure of approximately 1.5 billion dollars for technology, a substantial fraction of which went to what in retrospect is wasted effort at coordinating sub-systems development, integrating logistics and training considerations into the design, and laying out a production capability.

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*Laboratory for Progress, a resource of the technological achievements of the XB-70 and their application throughout the industrial complex of the USA. North American Aviation Co., 1964.

Experience such as that with the B-70 led the Director of Defense Research and Engineering (DDR&E) to issue a directive which established the project definition phase (PDP), now known as contract definition. This directive, in its latest version, defines six prerequisites which must be met before a major engineering or operational systems development project can be initiated.* The prerequisites are:

1) Primarily engineering rather than experimental effort is required, and the technology needed is sufficiently in hand.

2) The mission and performance envelopes are defined.

3) The best technical approaches have been selected.

4) A thorough trade-off analysis has been made.

5) The cost-effectiveness of the proposed item has been determined to be favorable in relationship to the cost effectiveness of competing items on a DOD-wide basis.

6) Cost and schedule estimates are credible and acceptable. These prerequisites would tend to inhibit the premature initiation of a project like the B-70 today. It would not prevent the development of the technology inherent in the B-70 if the planners of the Exploratory and Advanced Development

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*Department of Defense Directive 3200.9 dated July 1, 1965, Initiation of Engineering and Operational Systems Development.

program deemed such developments necessary and could make a reasonable case for such activities. This places a heavy responsibility on these planners. Naturally, if the value of achieving a systems capability quickly is very high, the contract definition procedures can be waived by DDR&E.

THE ENVIRONMENT IN WHICH MILITARY R&D IS CONDUCTED

The dominant characteristic of the environment within which developments are conducted is uncertainty. There is uncertainty as to the future detailed objectives of our military forces, there is uncertainty as to the future effectiveness of these forces and there is uncertainty as to the alternative means available for achieving these objectives. These uncertainties are external to the R&D programs. There remain many internal uncertainties. Will a particular technological approach to a development work as predicted? Will the components integrate together without serious interference? Will the subsystems be sufficiently reliable to permit the achievement of mission objectives? These are critical uncertainties and much of the literature of project management concentrates on the problems of how to effectively cope with these uncertainties. The external uncertainties that we want to consider are the uncertainties which remain even if the project meets all of its technical objectives. In essence, it is the uncertainty as to what the military "requirement" is and which of a number of alternative military systems will most effectively meet the requirement.

The most important reason for the dominant role played by uncertainties is the long lead time required for the development of military systems. Military systems typically require from five to ten years to go from early concept to useful operational capability. The lifetime of the system may be from 5 to 15 years. Thus the effectiveness of a system depends upon events which are at least five and perhaps 15 to 20 years in the future. The effectiveness depends in part upon decisions which our enemies themselves have not yet made. The result is that system planners seek systems which are dominant; which remain effective in the face of almost anything an enemy can do. Alternatively they may seek a simple extension of present capabilities, the so-called "higher-further-faster" school of planning on the assumption that such a system is bound to be better.

Not only is there uncertainty as to the nature of the threat we must face, but there is uncertainty as to the precise policy military power must support. During the middle of the 1950's, for instance, our concern was so dominated by the threat of a nuclear confrontation with the USSR, that we hardly considered questions having to do with more limited conflicts. The military services in large part shared this preoccupation but those that did not failed to get policy guidance in other areas from the national authorities. This type of uncertainty as to policy cannot be resolved by setting up better policy making organizations. Future policy will reflect the requirements of future alignments among the nations of the world as well as their military and economic capabilities. Moreover, this policy will depend in part on what we are capable of doing - thus upon our future military systems among other things. All of these remain uncertain.

Another source of uncertainty external to a particular systems development is the potential emergence of new technologies to provide alternative means of achieving a military end. A notable example of this type of uncertainty was reflected in the fate of the Air Force's cruise missile program. Both the Snark and the Navaho cruise missiles found themselves overtaken by the ballistic missile and both programs were cancelled before any useful operational capability was achieved.

The important quality of these uncertainties which are external to a program is that very little can be done to reduce them. It is true that improved intelligence and a better policy making apparatus might help the situation a little but the fact remains that the importance and effectiveness of a new military system depends critically upon decisions which will not be made or even considered for five or ten years. The implication of this situation is that the total development program of the military should provide a number of capabilities sufficient to meet all reasonable needs, not just the needs viewed as most probable. The program should have elements designed to hedge against uncertainties of the sort we have discussed. A partial solution to this problem may be the production of systems which have sufficient flexibility to meet a variety of contingencies.

The hedging can be accomplished in a variety of ways. It is possible to develop a variety of different systems. This is expensive but it represents the way in which the Air Force, at least, conducted its developments in the 1950's. The cost now seems prohibitive however, and the best alternative seems to be an active Advanced Development program. As the threat is more clearly perceived, parts of the Advanced Development program may be brought together into systems. There is no doubt that a system is more than merely a collection of subsystems. Considerable work is required to engineer a system and frequently new approaches to one or another subsystem are required. Consequently, hedging the uncertainties of the future using Advanced, and to some extent Exploratory Development, puts a premium upon the planning of Advanced Development projects so that subsystems technologies are available at the proper times to fit together into a system. Moreover, sufficient understanding should exist to allow adjustment to the subsystem performance during the systems development activities.

Summarizing the discussion to this point, we have made three observations,

1) The objectives of the military R&D program have several dimensions. These include the provision of information to decision makers and the provision of insurance against unexpected enemy developments as well as the more commonly considered development of military equipment.

2) The present structure of development activities as implied by the Research, Exploratory, Development, Advanced Development, and Engineering and Systems Development funding categories, is designed to provide an orderly progression of technology from concept into use. The procedures are supposed to match the magnitude of the technological risk; larger resource expenditures being associated with smaller technical risks.

3) The objectives of the future military forces together with the threat they will faceareuncertain and will remain so.

With these observations in mind we can pose several questions about the effectiveness of the military R&D program. For instance;

1) What is the proper balance between funding categories, and how stable should this balance be?

2) What qualities of the present DOD organization tend to enhance or reduce the effectiveness of the R&D effort?

3) Can guidelines be developed for structuring military research organizations.

THE DISTRIBUTION OF RESOURCES AMONG TYPES OF R&D EFFORT

The problem of choosing the allocation of resources among types of R&D activities is a difficult one. There are many who would maintain that basic research is not receiving sufficient support because of the tremendous amount of resources allocated to development activities. Others would maintain that too much effort is expended in Research and Exploratory Development where it is "wasted" on projects having no military significance. Instead, more effort should be placed on the systems development area which will result in a focusing our technological activities. In any short run situation there is little chance of choosing the winner of this argument. A few observations can be made however.

The size of the systems development effort will be determined by the degree to which newly developed equipment will improve our military effectiveness combined with a determination of the value of such improvements in effectiveness. We would expect the amount of systems development effort to be high when either a new technology giving a large increase of military effectiveness emerges or when a new threat is felt to exist. Historically, new technology and new threats do not appear continuously. There have been two major technological "revolutions" in the last twenty years, the development of nuclear and hydrogen weapons and the development of the ballistic missile. There have been perhaps three major threats perceived in this time period. The first two are associated with the achievement by the Soviets of the technological breakthroughs noted above. The third is the recognition that a strong nuclear force would not deter more limited types of aggression such as that in Viet Nam.

The consequences of the non-continuous appearance of threats and technology is that we should expect considerable fluctuation in the size of the system development budget over time and hence we should expect that the proportion of the total R&D budget that goes into systems development will fluctuate. When there is not a dominant technological development or a clearly new threat, our uncertainty about the future increases. Not only are we unclear about which direction to proceed but we suspect that our enemies are too. Thus, at the time at which the amount of systems development falls off, we should be seeking to increase the amount of hedging we do against these uncertainties. There should be a tendency for Advanced and Exploratory Development to increase when systems development decreases.

The determinants of the quantity of resources allocated to Research and Exploratory Development are somewhat different. These types of efforts are our sources of information on potential technological breakthroughs and insight into our enemies' technological programs. In these programs we would expect greater stability. We would seek to cover all possible technologies with a particular focus on those in which advances would appear to lead to significant increases in military capabilities.

In summary, we would expect there to be no uniquely appropriate balance of effort among R&D activities; instead we would expect that there would be a shift to or away from systems development as our uncertainty about the future decreases or increases in Advanced Development efforts and possibly Exploratory Development efforts.

The actual patterns of funding for the past three years are shown in Table 1. Unfortunately, the categories of development activity which we have been using have only recently been adopted and hence lengthy historical data are not easily assembled. These data show a small trend away from systems development (53.8% of total DOD, R&D effort for FY 64 to 47.1% in FY 66) and towards Exploratory and Advanced Development (25.8% of total DOD R&D effort in FY 64 to 30.1% in FY 66). If the figures went back to 1960 this trend would no doubt be even more apparent. The trend in part reflects the growth in uncertainty mentioned above but more importantly it reflects the infleunce of a group of decision makers in OSD who have forced the change in Research and Development procedures typified by DOD Directive 3200.9.

There is another interesting phenomena shown in these figures. The Advanced Development activities are a relatively small proportion of the total R&D program. Indeed, if one program, the Air Force's Manned Orbiting Laboratory (MOL) is eliminated from the FY 66 figures, the percentage of the total R&D effort expended in Advanced Development would remain relatively constant at 9 to 9.5 per cent. It is possible that this is an appropriate level of effort but there are some reasons to believe that the effort here may be low. To consider this possibility we turn to our second question, what is the impact of DOD organization on the effectiveness of the R&D program.

RDT & E PROGRAM FUNDING
(Millions of Dollars)

	Research	Exploratory Development	Advanced Development	Engineering and Operational Systems Dev.	Management and Support
Air Force					
1964	84.5	305.0	396.5	2184.7	654.6
1965	93.4	318.4	310.4	1845.8	637.9
1966	102.9	315.9	478.7	1610.5	668.7
Army					
1964	81.5	243.0	80.2	847.5	170.4
1965	91.4	237.7	111.1	714.7	221.4
1966	91.8	253.6	125.6	752.7	240.6
Navy					
1964	136.3	343.6	134.6	577.9	206.0
1965	124.5	338.3	150.6	566.5	185.8
1966	137.6	342.1	150.6	615.1	154.9
Advanced Research Projects Agency (ARPA)					
1964	46.0*	225.0*			
1965	44.7	227.3			
1966	47.0	230.0			

* 1964 ARPA Research shown as 17% of total ARPA Budget (1965 is 16.4%, 1966 is 17%) since breakdown is not given in hearings

RDT & E PROGRAM FUNDING (Continued)
(Millions of Dollars)

	Research	Exploratory Development	Advanced Development	Engineering and Operational Systems Dev.	Management and Support
TOTAL					
1964	348.3	1116.6	611.3	3610.1	1031.0
1965	354.0	1121.7	572.1	3127.0	1045.1
1966	379.3	1141.6	754.9	2978.3	1064.2
Activity as Proportion of Total					
1964	5.2	16.7	9.1	53.8	15.4
1965	5.7	18.0	9.2	50.4	16.8
1966	6.0	18.1	12.0	47.1	16.8

SOURCE: 1965 and 1966 Hearings before a subcommittee of the Committee on Appropriations, House of Representatives on Department of Defense Appropriations, Government Printing Office 1964 and 1965.

Note - 1964 and 1965 figures are those presented in 1965 and 1966 hearing respectively. 1966 figure is the budget request shown in 1966 hearings.

THE IMPACT OF DOD ORGANIZATION ON R&D EFFORT*

In the military services, Exploratory Development activities are almost wholely the responsibility of in-house laboratories. Systems development, on the other hand, is handled by a development or materiel command or bureau whose primary responsibility is planning and management rather than actual engineering. In the Air Force, Exploratory Development is the responsibility of the Research and Technology Division (RTD) of the Air Force Systems Command (AFSC). There are seven laboratories which, with several other specialized organizations, make up RTD.** These laboratories each have responsibility for a portion of the exploratory development funds.

Within AFSC there are four "product" divisions, the Ballistic, Space, Aeronautical and Electronic Systems Divisions (BSD, SSD, ASD, and ESD respectively). Each of these divisions has a group of system project offices (SPO's) having responsibility for the management of the Engineering and Operational Systems Developments assigned to the division. The present SPO system is the culmination of a long process of evolution in management procedures designed to direct and maintain control over the development of the increasingly complex systems used by the Air Force.

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*The observations in this section are based largely on Air Force procedures since this is the source of the author's experience.

**There is additional laboratory work conducted in biology and medicine at the Aerospace Medical Division (AMD) of AFSC.

These procedures are very detailed. They are designed to improve the probability that the developed system will appear on time, work as specified, and cost the amount originally estimated. They require careful specification of the detailed goals of the development. In the latest group of projects in which they have been used, they have performed reasonably well. Indeed they have performed very well by the historical standards of the Air Force. They have been used, however, on the type program which has gone through contract definition and thus presumably is based upon technology which is well in hand. This was frequently not true of Air Force projects in the 1950's so comparisons of todays' project performance with those of five to ten years ago may be a bit spurious. In any case, the product divisions are end-use oriented, and have a highly developed set of procedures designed to effectively translate technology into operational systems. The Research and Technology division is far more concerned with science and technology. RTD was formed in 1962 in order to improve the quality of the Air Force laboratory effort. The work of these laboratories had frequently been dominated by the requirements of system developments. As a result little creative new work was being done and there was considerable dissatisfaction in the scientific community with the quality of the labs. RTD has spent a great deal of effort in improving the laboratory activities. Its very formation freed the laboratories from much activity directly in support of system development. In addition procurement procedures were modified, improved planning procedures instituted, and personnel policies revised. The effects of these changes will not be seen clearly for some years, but it is clear that much effort has been expended in considering the nature of Exploratory Development tasks and the procedures which promise to improve the performance of these tasks.

Thus, in the spectrum of development activities from Exploratory to Operational Systems Development, both ends have received considerable attention. The same cannot be said for Advanced Development. On either end of the development spectrum, the objectives of the performing organization can be translated into fairly straightforward criteria. In the case of systems development the criteria are the degree to which plans are fulfilled, and the objective is to develop an organization and procedures which enhance our capability to deliver a product according to the original plans. In the case of exploratory development, the criteria are the quality of the technical work and the objective is to improve it. In the middle of the spectrum, criteria are more difficult to establish. On the one hand, the objective is to explore new technologies and do novel technical work. On the other hand, the size of the average project is such as to require firm management control.

The solution adopted by the Air Force is to divide the Advanced Development tasks into two groups. One group is considered to have many of the attributes of systems. The projects are large and complex and are judged to require systems management. These are assigned to the various systems divisions and are managed with many of the same procedures as Operational Systems Developments. The other group of tasks which tend to be smaller and to have more diffuse objectives are assigned to laboratories for management.

The result of having a program made up of so many diverse elements is that no single set of procedures can cover the program. Indeed within AFSC there have been only a few instructions giving general guidance in the planning and conduct of Advanced Developments, although there are now several manuals nearing completion which have relevance to this type of activity.

While the absence of detailed formal procedures and instructions can be viewed as giving a desirable freedom to program planners, it can also lead to attempts by planners to avoid using this category of development because of a lack of guidance and appreciation of its role in the total development process. It may also be true that programs are submitted in this funding category which properly belong in other categories because of a lack of appreciation of the objectives of Advanced Development programs.

There is another difficulty associated with Advanced Development projects. In order to obtain better control over these activities each major project has a separate program element in the program budget. Occasionally a group of projects having similar objectives are lumped together to form a single element. To obtain such an element a program change proposal (PCP) must be submitted through Hq USAF to OSD. This must be approved before funds can be obtained. Seeking such approval is time consuming and requires considerable effort. Moreover, the review process may tend to eliminate projects which have payoffs far in the future or high technical risks. In other words the procedure for obtaining approvals for Advanced Development Projects may result in a conservative program.

The situation is complicated further for advanced development projects which are closely tied to proposed systems. There frequently appears to be a reluctance to initiate advanced development on components if the division feels there is a chance a program for a development of the total system will be approved. The divisions prefer to develop a total system rather than a single subsystem for later integration into a program. Their orientation is towards delivering products to the operational forces and they frequently view work on a single part of a system coupled with a delay on the definition of the entire system as slowing down their efforts to meet their objectives. Again, the effect of this is to reduce the number of projects in Advanced Development.

In summary, then, there are three reasons to expect that within the Air Force there may be a bias tending to reduce the number of Advanced Development Projects.

1) There are few standard procedures to guide the formulation and management of such programs.

2) The review and approval process required to establish a project may deter the initiation of some desirable projects or result in the rejection of some which are proposed and should be initiated.

3) The preference of the managers of some of the programs is to wait and do most of the work as a part of the system development.

These reasons should not be viewed as simple organizational "cussedness". They reflect the very real problems of this particular type of development program, the combination of relatively large technical uncertainties with relatively large resource requirements.

SOME GUIDELINES FOR STRUCTURING MILITARY RESEARCH ORGANIZATIONS

To begin discussion of more positive guidance for structuring military R&D organizations we introduce two concepts which are useful in thinking about Research, Exploratory, Advanced and Systems Development. In crude terms it seems possible to break these activities into two categories requirements-pull and technology-push efforts.

Requirements-pull efforts are those projects which are undertaken to fulfill needs which are clearly recognized by a large segment of the total organization, the DOD. The organization recognizes a need and perhaps even an operational means for meeting this need. They then turn to the R&D organization and say do what is necessary to fulfill this requirement or need. In passing it should be noted that this is the "comfortable" way for the entire organization to proceed. It appears that it knows where it is going and is able to direct its R&D resources toward efficiently fulfilling these needs.

On the other hand we must recognize that "needs" (and our ability to meet them as expressed in operational concepts), frequently do not become clear until scientific breakthroughs, often unexpected, are made. Our historical experience with nuclear weapons, rocketry and in numerous less spectacular areas supports this observation. As a result of this realization we support many activities that we might call technology-push activities, hoping that some breakthrough will provide the potential for new capabilities which will in turn lead to recognize new ways to meet needs. Naturally, requirements-pull efforts are likely to follow technology-push efforts to aid in achieving the potential revealed by the latter.

One of the problems with technology-push types of projects is that they require faith on the part of people outside the project. The payoffs are not obvious. Resources spent in this fashion have to compete with the seemingly more attractive opportunities in requirements-pull areas where needs have been recognized. Support of such activities is not a comfortable way for an organization to work.

After one has worked with these concepts for awhile, at least in the terms we have discussed, they seem to break down. Basically, the problem is who perceived the requirement or need. It is possible to find someone who can perceive a usefulness for almost any project; who can suggest some conceptual requirement that the project is working towards. Thus it is possible to say that all efforts are requirements-pull efforts, at least beyond the very early research stage. But the concepts of requirements-pull and technology-push are appealing and seem relevant to our experience. To remove this ambiguity, we redefine the terms. Technology-push efforts are those efforts where the research personnel determine what research efforts will contribute to needs as they, the researchers, perceive them. Requirements-pull efforts are efforts where the needs are perceived by those external to the research efforts; the research is initiated by planners and operationally oriented organizations. When phrased in this manner it can be seen that the distinction between technology-push and requirements-pull efforts is largely a distinction in who decides that they shall be conducted. If the decisions are made at the top of the organization we have clear requirements-pull efforts. If they are made at the bottom, by the individual researchers, they are technology-push. There is a vast middle ground between the top and the bottom and clearly the distinction is not perfect. It is still useful however when we come to think of the distinctions between Research, Exploratory, Advanced, and Operational Systems Development activities.

Considering first the Advanced Development category of activities, we continue to distinguish between projects such as the MOL, which are included solely because of their size is such as to lead top decision-making to place them in a development category where they merit line item control, and projects which appear because they represent a logical step in a development process between raw technology and full scale product development. We shall ignore projects such as MOL. The bulk of the remaining advanced developments represent attempts to advance particular components of full systems to a point where rational decisions on the development of full systems can be made. These efforts are undertaken with a pretty clear view of the end systems requirements which they may ultimately help to fulfill. These efforts are pretty clearly requirements-pull efforts and quite rightly the decisions on them are made at a fairly high level.

In contrast to this, the basic research program is certainly a technology-push effort. Here the initiative is taken by the labs themselves and most projects begin at the initiative of the individual researchers. These researchers do not act in a vacuum. They know the mission of the military service for which they work and in most cases probably attempt to relate their activities to the missions of that service in an intuitive fashion. Because the end use of activities in this area is so obscure, we do not often attempt to evaluate the work done on the basis of its immediate contribution to the military but rather upon its professional merit. The key to the success of these activities is not proper project selection but proper personnel selection and an ability to convey the basic needs of the military service to the lab staff informally and in broad terms. (It should be noted that the success of Bell Lab's research activities can be attributed to attracting good people <u>and</u> the fact that the mission of the lab is clear; to exploit technology that is likely to improve communications.)*

When we turn to the Exploratory Development activities, we can immediately see a problem. These activities are in the middle between efforts which would generally be considered requirements-pull and those which are considered technology-push. Hence procedures appropriate to one or the other of these types of activities will not be universally applicable to Exploratory Development. On the other hand, the people required to obtain really useful results must be capable of the same independent judgment as the basic researcher while, on the other hand, the output of the lab must have a high degree of relevancy to the military's immediate problems. The key to success in this area is clearly in the personnel and most particularly the lab director. He is the person who, as a professional researcher, can provide the critical support of the researcher, while, through his knowledge of military needs, he can guide the researcher's work into useful channels.

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*Richard Nelson, P-1845-RC, The Link Between Science and Invention: The Case of the Transistor.

This meeting of technology-push and requirements-pull efforts within a single organization makes for considerable difficulties in setting up organizational objectives. Yet it is important to have such organizations. They provide the transition of ideas from one stage to the other which would be a very difficult process if technology-push efforts were the responsibility of essentially one set of organizations while requirements-pull efforts were carried on by another set. To gain insight into proper goals organizations in the Exploratory Development area let us again turn to the more polar cases of Research and Advanced Development.

IMPLICATION OF DIFFERENT LAB RESPONSIBILITIES FOR THEIR STRUCTURE AND PROCEDURES

In the area of research, heavy reliance is placed upon the decisions of individual researchers and hence there is a need to attract the very best research minds. Such minds are attracted by stimulating discipline areas, outstanding colleagues, and a minimum of distracting administrative procedures. The greatest possible freedom in the use of funds should be given to the laboratory director. What is probably most important here is that there be relative stability in funding levels so that the cost and administrative burdens as well as personnel conflicts associated with ups and downs in activity levels are minimized. It would seem highly desirable to make as much of the work in-house as possible to promote stability and to minimize the burdens of contracting.

When peculiar skills are needed which are not available within the lab, there should be easily arranged consulting arrangements. Some small amount of contract work for use of special facilities will be necessary. In general, however, it seems desirable to make basic research laboratories fairly self-contained.

In contrast, in the Advanced Development area we would expect considerable instability. Projects which enter into Advanced Development should pass some test of value versus cost and there is no reason to expect that exactly X dollars worth each year will meet that criteria. Moreover, there may well be times when we will want to shift emphasis from the essentially option buying activities of Advanced Development to more active exploitation of systems developments.

The type of person involved in these activities is different also. Larger teams of individuals with less independent bents are required to do the detailed engineering work. These people should not be allowed to decide what they want to do although they should have some say about how they want to do it. Finally, these efforts are aimed at demonstrating feasibility for production and in a real sense represent the transition of an idea from concept to reality. Since the reality, if it ever appears, must be manufactured, it seems desirable to have most of these developments conducted by contractors so manufacturing problems are realistically considered. Making the Advanced Development effort primarily a contractor effort has an additional advantage. It allows the bulk of the instability in funding levels to be reflected in the activities of the contractors who can adapt more readily than government organizations.

Exploratory Development again forms the middle ground. Less freedom should be given the lab director here than in basic research but he certainly should not have a great deal of day to day pressure put on him from higher authorities. Less stability should be expected in funding than in Research but considerable stability in-house effort is necessary to retain the quality personnel needed. There is more reason to emphasize the contract activities than in basic research because increased proportions of the work will require specialized manufacturing and test facilities.

Yet as we have noted, in Exploratory Development there remains a very important need for the individual initiative inherent in technology-push efforts which means that really high quality personnel must be attracted and retained. This requires the same qualities of freedom of unnecessary administrative burdens, relative freedom of choice of projects, and intelligent leadership as basic research. The question is how to achieve these ends and indeed to what degree have we achieved them so far.

Summarizing this point we suggest:

1. The various types of R&D activities require vastly different types of personnel and leadership as well as

different degrees of in-house/contractor participation. Combining the Research, Exploratory Development, and Advanced Development activities in one laboratory is likely to lead to great difficulties in establishing laboratory procedures and obtaining good laboratory leadership.

2. The qualities desired in the lab director differ between basic Research and Exploratory Development. In Research the need is for professional judgment. In Exploratory Development there is a need for a (rare) combination of professional and mission judgment. This probably suggests that civilian scientists are appropriate leaders for the basic research labs. In the labs responsible for Exploratory Development either military or career civil servants are likely to possess both the required capabilities. Outside civilian scientists are likely to lack the necessary insight into military missions.

3. Both Research and Exploratory Development labs would benefit by reducing administrative burdens associated with contracting. In Research this appears to be most usefully accomplished by making the labs largely in-house activities. In the Exploratory Development labs, contracting procedures should be highly tuned to research requirements; being fast, using a minimum paperwork, and using a maximum of individual buyer initiative.

We emphasized the need for quality personnel. One of the factors that will be important to a researcher is his image of the difficulties that he will have in selling his projects. If people fairly far above him and the lab director have to be sold this will appear forbidding indeed. An important factor to him will be the degree to which the lab director can unilaterally determine the utilization of funds.

Finally, within the Exploratory Development most management from higher headquarters should be by review. On-line management delays and disrupts work and, given the relatively small amounts involved per project, is likely to cause more harm than good. The lab director should be given great authority and each year or every six months be required to render a comprehensive report.

The ideas advanced in this chapter do not provide unified, clearcut guidance for the conduct of the military research and development program. Rather they are intended to indicate the wide variety of considerations which must go into structuring and conducting such a program. The objectives of the program are diverse. The means for achieving these objectives are many. The importance of the structure of the organizations conducting R&D activities should be clear. There is no obvious best allocation of resources or structure of development organizations. About the best that can be hoped is that some of the concepts advanced in this chapter will prove useful in thinking about policies for military research and development.

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