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March 1963

P-2717

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The Air Forces' ability to perform its missions in the future decades depends critically upon the research and development it is doing now and will do in the immediate future. The importance placed on these activities by the Air Force is indicated by the fact that some $3.8 billion has been requested in obligational authority for Fiscal 1963, some 34% of the total procurement and R&D budget. Because of the importance of research and development both in terms of the future capabilities of the Air Force and the quantity of resources allocated, RAND has for some years been studying the R&D process with the objective of seeking better ways to conduct such programs. This talk reports some of the notions we have formed on the basis of a considerable number of case studies of Air Force development projects. The bulk of these studies have dealt with aircraft developments, airframes, engines, and electronics. The generalization of them to missile and space systems may be somewhat risky but our casual observations lead us to believe that many of our findings apply equally well. It should be emphasized that we

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This is the text of an informal talk given to a seminar for the procurement personnel of the Space Systems Division in Los Angeles, 6 March 1963.

are concerned largely with the development of systems that will actually enter the weapons inventory. Thus we are not considering the problem of how to conduct programs similar in scope to the X-15 program but rather ones akin to the B-70, Minuteman, and Titan III which have or had high expectations at the beginning of their development of becoming production items.

SOME SUGGESTED CHANGES IN R&D STRATEGY

Throughout this discussion I will devote a great deal of attention to what I shall call advanced experimental hardware or prototype developments. These words have many varied meanings so let me spell them out a bit more clearly. This type of hardware should have the following characteristics:

- Primary effort should be aimed at getting test articles which resolve the technological uncertainties in a design solution rather than in obtaining an article which is an exact image of what the final configuration is thought to be.
- Speed in getting these test articles is emphasized.
- All possible efforts should be made at minimizing costs in those areas which do not contribute to the successful fabrication of the test articles.
- Little or no effort should be aimed at implementing the production of the system prior to its testing.

With these notions in mind let us turn to our suggested changes. There are perhaps three shifts in emphasis implied in our suggestions. First, a greatly increased use of prototypes or advanced developmental hardware of the sort I have mentioned would be emphasized. The efforts put into this phase of the development are purely and simply aimed at resolving technical uncertainties inherent in hardware which will be able to perform the mission in question.

The second shift in emphasis which we suggest is an increased number of parallel component development programs, of the sort I have outlined. Given the limited research funds available, such an increase depends in an important way upon the reduction in the cost of any single program. I think that programs conducted in the fashion I have suggested will be considerably cheaper through the testing stage. And it is at the end of such a test program that the best design or designs should be selected for further development. I must emphasize that at the end of this testing phase the designs are in no sense completely developed. What you do have is a design in which you have sufficient confidence to allow you to go ahead full speed on a development effort, and you have good information to help in choosing the particular design for such development.

Finally, we would propose that a much decreased emphasis be placed on weapon system activities in the early phases of the development. The emphasis should be on developing components which demonstrate the desired capabilities before such components are wedded into systems.

Putting these ideas in a somewhat different way, we would view the development process as having three stages. The first stage would be the generation of proposals by the manufacturers competing for the development responsibility. These proposals should in all likelihood be considerably less detailed than those presently being submitted. The second phase would be the building of expedited development hardware with the characteristics I have mentioned. If the budget allows it, there would be the development of at least two different design solutions. On the basis of the testing of this hardware, a design would be selected for further development and production implementation. This may be contrasted with the present system which is essentially two stages, an extended paper competition and development and production implementation of a design chosen in this paper competition.

These ideas imply a process very much like that used in "the old days" and indeed it is. We think that a bit more emphasis should be placed on the experimental aspects of the development and a bit less on achieving a finished piece of hardware than seems to have been the case in the old prototype programs but basically there is little difference. But the increased emphasis placed on weapon system responsibility and concurrency grew out of shortcomings or supposed shortcomings of the old system and with some good reasons. We do not mean to suggest that these concepts be abandoned entirely. What we do suggest is that they not be brought to bear until after the second phase of the development, until after the technical characteristics of the design of the various components are well understood. The problem with weapon system developments has been that the characteristics of the component subsystems have virtually always changed in the course of the development process necessitating extensive and expensive changes in the other subsystems to compensate for such changes. Our suggestions amount to expediting the resolution of such technical uncertainties before attempting to optimize a weapon system design. The same is true with concurrency. It is important to have the main technical parameters well in hand before beginning the concurrent design of facilities and support equipment.

An approach such as the one we suggest places considerable responsibility on the Air Force to see that a group of component developments are underway so that when it does come time for the weapon system integration to begin, suitable components are available. In particular, it probably means a considerably larger and continuing component development program.

THE BENEFITS OF SUCH AN APPROACH

What would be the advantages of such an approach? In large part, the advantages depend on what I consider the most important single factor in the development process -- uncertainty. There is uncertainty as to the strategic environment the weapon will face, uncertainty as to the technical performance of the components of the system, and there is uncertainty as to costs of the system components and hence of the system itself. How then do our suggestions help in facing such uncertainties?

First, our approach will tend to provide better information at an earlier point in time and, hopefully, at a reduced cost. The technical feasibility of a design solution and some implications for costs should be better understood after the early tests are completed. On the basis of such tests the most promising design solution can be picked for further development. Moreover, in cases where parallel approaches have been taken, there is some insurance against the technological uncertainties inherent in a particular design.

The increased use of advanced developmental hardware should also lead to a broadening of the technological base of the defense industry since a wider range of projects could be undertaken. This has the advantage of providing a hedge against environmental uncertainties, the uncertainties of what the future threat will be.

Thus we would have been better prepared to meet the challenge of the shift in emphasis from the fighting of central wars to fighting of limited wars if we had not let the technology needed for such activities languish for several years in the late 1950s. The reasons for this are many and varied but in large part I think are due to the fact that it was felt that the only way to develop a system was the weapon system-concurrency route and that any such development involved many hundreds of millions of dollars. In a sense our development philosophy priced these developments out of the market. In contrast, had a broad based technological program in the areas of engine, guidance, and airframe development been underway, we would have been able, when the need arose, to enter into a weapon system development with a reasonably well understood technology inherent in the advanced developmental hardware.

A closely related benefit is the improvement in decision making which might accompany such a development program. Decisions are often slow or wrong because of just the uncertainties I have been mentioning. Consequently, the quick resolution of uncertainties at a reasonable cost should promote better decisions on which system to buy. But an equally important consideration is that the lower initial commitment together with some hedging through parallel development makes the initiating decision somewhat easier. This should lead to the more timely initiating of development projects and hence an earlier resolution of the technical uncertainties I have mentioned.

The use of advanced developmental hardware has one further advantage for decision making. The DOD calculations used in choosing among alternative weapon systems seem to be largely based upon tangible mission effectiveness measures, emphasizing effectiveness criteria which can be measured at least conceptually. They may well leave out a number of important intangibles. It is my feeling that a number of operating pieces of hardware which can demonstrate some of the intangibles of flexibility, controllability, and intelligence would be much more effective in presenting the Air Forces' point of view than the simple exhortations of high level command officers, or The RAND Corporation for that matter. In sum, such a component prototyping program would make the planning of both the Air Force and the DOD more realistic and flexible. And to the extent that the Air Force is given enhanced control over the R&D budget, subject only to general guidance from the DOD, such a program would regain some of the initiative in development activities which has recently been lost to the DOD.

Finally, since these proposals imply more development projects of a creative nature, they offer the possibility of reestablishing some of the useful competition which seems to have been lost in the defense industry in recent years. Hopefully the fine art of brochuresmenship will become less important and the actual design will become more important in the minds of the companies in the defense industry. It is said that good engineers lose their creativity if they are not kept busy in useful engineering activities and this proposal has the merit of providing more actual design and development work than is being provided with the present development policies.

Let me digress for a moment to mention one or two examples of the kind of program that I am envisioning. They are relatively few and far between. The B-47 is a good example. For less than $20 million, two prototypes were built of what was then a fairly radical design with considerable uncertainty as to its performance characteristics. This $20 million was in no sense the total development costs, in fact it may be looked at as about 15% of the development costs. What then did the prototype provide? It allowed the making of a development and procurement decision with high confidence that such a development would be successful. It allowed the discarding of several other designs which in retrospect would have provided considerably less capability than the B-47. And to the degree that we are able to estimate such things, it seems to have given us a somewhat cheaper development program. The cost of providing insurance in the form of parallel airframe development programs seems to have been in the order of $60 million.

The second example is the Sidewinder missile developed by the Navy. This development was conducted with a great deal of experimentation and with very small commitments. Parallel development paths were followed whenever there seemed to be particular uncertainty concerning a component of the system. The total cost of less than $35 million for development of the initial passive system compares very favorably with the development costs of the Falcon which approximated $400 million for the active radar version and a further $120 million for the infrared version.

As I noted at the beginning of my talk, our experience at RAND in research and development strategy has been largely concentrated in the aircraft field. But the notions which seem important there seem equally important in space. Some of our space systems seem to have suffered from the application of weapon systems planning too early in their development. In fact since continued testing of a system, which is possible in aircraft systems through continued flight tests, is extremely expensive in the case of space systems, this probably argues for even greater efforts being placed on component development and testing before such components are combined into a system.

In the booster field, I am impressed with the changes in guidance and reentry vehicles during the evolution of the Atlas program. Such changes lead me to feel that the independent development of these systems with only broad systems guidelines through the early part of the development process is feasible and will in fact lead to more reliable and less expensive systems developments.

IMPLICATIONS FOR CONTRACTING

What then are the implications of such development philosophies for contracting? Remember now that I am talking about the initial stages of the development process and that my suggestions apply to that portion of the process.

A most important implication is that there should be a considerable relaxation of requirements for progress reports, data reports, and other routine red tape generally used to monitor projects. The contractor should be allowed to spend most of his time on the creative part of the design and should have a maximum of flexibility in his decision making. Anything not absolutely necessary for obtaining test hardware should be eliminated. Such relaxation can be allowed because the test vehicles or components developed are not viewed as the final version, there should not have been an enormous sum of money committed, and the future of the Air Force should not be riding on any one project. In other words the tight control in the form of required contractor procedures can be relaxed a good deal in order to allow the contractor to have as great freedom as possible.

It is not at all clear that the contractors would be terribly happy about a proposal such as this. I have been struck by the fact that the senior technical people have almost always felt that this proposal would lead to superior technical results at a much smaller cost whereas the senior management people, mostly in costing and contracting, have maintained that it couldn't be done. The fact is that there would be in this initial period at least, and I hope in the later parts of the programs too, considerable reduction in the contractor manpower requirements. Such a reduction would of course lower the cost base and reduce the fees earned by the contractors unless such fees were increased as a percentage of cost.

A second concomitant of the approach I am proposing is the need for strong contracting officers located at the contractors' plants. These contracting officers should have a great deal of freedom in making decisions concerning the contract. Approval of subcontractors, most contract changes, and vendors should be made without resort to higher levels. Timeliness of decisions is very important. Again such procedures are possible because of the relative smallness of each individual commitment. Such flexibility allows the contractor to adapt quickly to problems which arise in the course of development.

Third, contracts for this type of research and development activity should eliminate any requirements for reliability groups, value engineering, or management systems such as PERT. It is the contractor's responsibility to design a reliable system which is producible and which shows up for its evaluation on time. Since his real incentive is to obtain a production contract, this will enforce these requirements. It may be that such requirements are appropriate for later phases of the development process but in the early stages of the process with the large uncertainties in design and fabrication features, such a superstructure does not contribute to the early and relatively inexpensive testing which I have suggested as being appropriate to projects of considerable difficulty.

The last two of my suggestions are of a considerably more speculative nature than the first three. I would be quite happy to hear your comments on them. Fixed price contracts have considerable merit. They tend to shift much of the risk in a development activity to the contractor where it properly belongs; they are a particularly strong incentive to contractor efficiency; and they reduce the requirements for Air Force supervision. The increased number of smaller development contracts inherent in our proposals holds out the possibility that fixed price contracts could become more frequently used. Naturally there must be competitive bidding for such contracts and thus the contract must be of such a size that a sufficient number of firms would want to bid on them. The use of such contracts would probably contribute much to the small business program, to the reduction of negotiated contracts, and to the spreading of defense business among more firms. The use of such contracts for development activities deserves further study.

My final proposal is only indirectly related to the R&D strategy changes which I have suggested. A concomitant of these changes is a wider based development of technology directed by the Air Force and other services. Such an increase in creative research effort lessens the need for the Air Force to support research by military contractors in the form of allowing research components in the overhead charges. Moreover, much uneconomic activity in the area of proposal preparation is supported through overhead accounts. The incentives on the companies to control these costs are a good deal less than if they were supplying the money out of funds which would otherwise be available for investment or distribution in the form of dividends.

At present these expenditures go to increase the cost base against which fees are computed. Some part of the research and proposal activity is of course of considerable value to the Air Force, but it is almost certainly of great value to the contractor too in helping him to develop capabilities and opportunities to obtain future work. I would suggest then the possibility of making such costs unallowable in the cost of the contract. In partial compensation some, perhaps considerable, increase in fee should be granted. Such a change might lead to considerably more economical allocation of resources in these areas than is presently promoted by the contracting system.

In conclusion, the process of research and development is a far different process than production. It seems reasonable to feel that the contracting procedures for R&D would be far different than for production. If the proposals I have suggested for changing the emphasis in research and development are adopted, the contracting procedures should change even further.

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