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COMPETITION AS AN ACQUISITION STRATEGY: IMPACT OF COMPETITIVE RESEARCH AND DEVELOPMENT ON PROCUREMENT COSTS

James P. Bell

November 1983

Prepared for
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This study examines the impact of R&D prototype competition on subsequent procurement costs for major weapon systems. Four acquisition programs that included prototype competitions are studied in detail, and cost growth data are compared for 14 programs that included prototype competitions and 27 that did not. There is evidence that prototype competition, when properly structured, does lead to lower procurement costs. For three of the four programs studied in detail, cost savings appear to be greater than (Continued)

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incremental costs of staging their competitions, on a constant-dollar, discounted basis. The study suggests that prototype competition should be continued (in a particular program) until the contractors can prudently propose firmly priced production options. Whether or not prototype competition should be initiated for a particular program depends on factors specific to that program.

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PREFACE

This study has been conducted by the Institute for Defense Analyses (IDA) for the Office of the Deputy Under Secretary of Defense (Acquisition Management) under contract number MDA 903 79 C 0018, Task T-3-173, dated February 22, 1983.

The purpose of this study was to examine the economic relationship between prototype competition in R&D and subsequent production costs for major acquisition programs. Study findings indicate that R&D prototype competition is a useful tool for the control of eventual production costs.

This final report is submitted in fulfillment of the contractual requirement.

ACKNOWLEDGMENTS

This study was made possible only through the generous assistance of the project management offices (PMOs) for the Apache Attack Helicopter System, the Abrams Tank System, the Sgt. York Air Defense Gun System, and the Air-Launched Cruise Missile System as well as Hughes Helicopters, General Dynamics Land Systems Division, Ford Aerospace and Communications Corporation, and Boeing Aerospace Company. Officials of these organizations provided the author with data and invaluable insights into the workings of prototype competition. Colleagues at IDA, especially Dr. R. William Thomas, provided valuable comments to improve this report. Nevertheless, the opinions expressed herein are those of the author and not necessarily those of the organizations contacted or of IDA. The author is also grateful for the support of IDA's library staff, for the editorial assistance of Eileen Doherty, for the efforts of Geneva L. Campbell in preparing the original manuscript, and for the help of Bernie Aylor, Andrea Clouser and Debbie Smallwood in preparing the final manuscript.

EXECUTIVE SUMMARY

This study explores the use of prototype competition during the R&D phase of major weapon acquisition programs as a tool to control eventual procurement costs. The research was performed for the Office of the Deputy Under Secretary of Defense (Acquisition Management) and considers a number of programs that initiated prototype competitions during the 1970s and that have now progressed to the point that procurement cost impacts can be assessed. Procurement cost growth has been compared for samples of 14 programs that included prototype competitions and 27 that did not, utilizing data from the Selected Acquisition Reports (SARs). In addition, case studies of four acquisition programs that included prototype competition were performed, in order to identify how competition achieves its results and to verify that favorable cost results were indeed attributable to the use of competition. The case study programs were:

- AH-64 Apache Attack Helicopter System
- M-1 Abrams Tank System
- M-247 Sgt. York Air Defense Gun System, and
- AGM-86B Air-Launched Cruise Missile System.

These case studies were based on the available literature as well as on visits to the respective Army and Air Force project management offices (PMOs) and the winning contractors.

In this study, R&D prototype competition means the funding of parallel development programs for a weapon system, including the design, fabrication, and testing of prototype systems to meet a common set of requirements with the intent of choosing only one of the designs for further development and/or production. Provided such a competition is well-structured, it can be expected to motivate the development contractors to take steps during the early design stage to control the potential production costs inherent in the system's design. The contractors also can be motivated to control production costs as the system is transitioned into production, through producibility changes in its design and in production methods.

In a well-structured competition, the development contractors would believe that control of eventual procurement costs is essential to their chances of winning a competition that they want to win. The principal elements needed to induce such a belief are assumed to include:

- The value of winning the follow-on contracts should be adequate.
- It should be possible to match up credible opponents.
- Procurement cost should be an important criterion for selecting the follow-on contractor.
- The Government should be able to validate the procurement cost estimates of the development contractors.
- The competition should result in production options with competitively determined ceiling prices.
- The development contractors should believe that competition could be reintroduced during the production phase.
- The contractors should accept financial responsibility for correcting design deficiencies in production systems.

Among these elements, the key to the control of eventual procurement costs is the requirement to propose production options with firm ceiling prices. Price ceilings can motivate the contractors toward a more intensive design effort to control procurement costs during the competitive phase since their price proposals must be low enough to win but realistic enough to be profitable. For the same reason, price ceilings can motivate the winning contractor to continue cost control efforts during the critical transition-to-production phase following the source selection, even if the contractor is then in a sole-source position. Further, the contractor's demonstrated ability to control costs during execution of the initial production options will aid the Government in obtaining a reasonable price during follow-on, sole-source production negotiations.

Four principal questions have been addressed by this study. These questions, together with the relevant study findings, are discussed below.

1. Does Prototype Competition during the R&D Phase Result in Lower Procurement Costs?

The study has identified evidence that, on average, R&D prototype competition does lead to less growth in unit procurement cost (UPC). Moreover, the extent of such cost savings depends importantly on the manner in which a competitive program is structured.

Information from the Selected Acquisition Reports (SARs) suggests a general tendency for programs that include R&D prototype competition to undergo less growth in UPC than other programs. The median annual change in estimated UPC was found to be 3.1 percent for 14 competitive programs and 5.8 percent for 27 noncompetitive programs. These growth rates reflect the experience of the various programs from the beginning of full-scale engineering development (FSED) until December 1982 and exclude growth due to inflation. It would be hazardous to draw firm conclusions from this comparison, particularly since

UPC growth is influenced by many factors besides R&D prototype competition. Nevertheless, an examination of certain characteristics of the programs in the competitive and noncompetitive samples does not reveal any obvious discrepancies sufficient to explain the difference in UPC growth rates. That is, the competitive and noncompetitive samples are similar as regards:

- Diversity of weapon types,
- Age of programs,
- Change in procurement quantities,
- Cost growth due to engineering changes.

The major dissimilarity identified was that the median competitive program was more than twice as large as the median noncompetitive program (based on estimated total procurement costs at the beginning of FSED), but the influence of size on cost growth is not at all clear. Also examined was the possibility that prototype competition prior to FSED leads to higher UPC estimates at the beginning of FSED, and hence artificially lowers measures of subsequent UPC growth. The evidence on this point is limited but does not support this possibility.

While the discussion above indicates that the measured difference in median UPC growth rates can plausibly be attributed to the use of R&D prototype competition, it has not been possible to estimate the amount of that difference with any precision. Indeed, a 95 percent confidence interval for the true difference permits estimates of the median UPC growth rate for programs without prototype competition to vary from 2.2 percent below to 5.0 percent above the median for competitive programs. The median for programs without competition can be estimated to be clearly above the median for competitive programs with only a 77 percent level of confidence. The inability to make more precise estimates is due to the small number of programs available for comparison as well as the considerable variation in UPC growth rates among these particular programs.

Case studies of the four particular competitive programs provided more conclusive, albeit less general, evidence. They revealed a large number of specific examples of procurement cost savings that would not have occurred without competition. These examples occurred at each step of the development cycle:

- Major design innovations reduced cost and improved performance.
- Costly design features were avoided without degrading system capabilities.
- Cost/performance trade-offs eliminated certain capabilities that the contractors found (with Service encouragement) to be too costly in light of Service priorities and design-to-cost (DTC) goals.
- Producibility changes to designs and production methods had important cost-reducing impacts.
- Production contract prices as such (and contractor profits) were lowered due to competitive bidding.
- Competitors agreed to unusually favorable contractual terms and conditions.
- Contractors made capital investments they otherwise would not have made.

Further, among the four case studies, it was found that UPC growth rates tended to depend on how well-structured a competitive program was:

- The AH-64 Program did not result in competitively priced production options, the competitive prototypes did not integrate mission subsystems, and annual UPC growth was 9.9 percent.
- The M-1 Program did integrate subsystems, included competitively priced production options (but only for recurring unit hardware cost and only for 6.5

percent of the total buy), and annual UPC growth was 4.3 percent.

- The M-247 competition included fully integrated prototypes, resulted in priced production options covering most procurement costs for 45 percent of the total buy, and UPC growth was -0.3 percent.
- The AGM-86B competition included integrated prototypes, comprehensive priced options covering 21 percent of the total buy, pilot production of 24 missiles by each competitor, and a UPC growth of 2.3 percent.

For both the AH-64 and the M-1, cost growth was lower for the specific hardware items emphasized in the prototypes than for the UPC overall.

2. Do the Downstream Savings from R&D Prototype Competition Compensate Adequately for the Incremental, Up-Front Costs of Using Competition?

For three of the four case studies, estimated procurement cost savings were greater than the incremental costs of competition. The ratios of savings to costs depended heavily on how large procurement costs were relative to the incremental costs of competition.

In order to estimate the savings from the use of R&D prototype competition, it is assumed that, without competition, unit procurement cost (UPC) for the four case study programs would have increased at 5.8 percent per year. This is the same rate at which UPC grew for the median noncompetitive program discussed above. Under this assumption, there were no savings from the AH-64 competition, but there were substantial savings from the M-1, M-247 and AGM-86B competitions. In dollars escalated for inflation, these savings amounted to more than $1 billion for each of the last three programs. Further, the estimated savings for each of these three programs were substantially greater than the incremental costs of holding the respective competitions. Here, the cost of competition is estimated as one-half the cost of the competitive development contracts. If the estimated savings and costs are expressed in constant (i.e., non-inflated) dollars and discounted (at ten percent, to take into account the fact that the costs are incurred up-front while the potential savings are realized only in the future), then the ratios of estimated savings to incremental costs are as follows:

- AH-64: -
- M-1: 2.4
- M-247: 9.9
- AGM-86B: 1.2.

Differences in these ratios reflect not only how well-structured the respective competitions were (as noted above), but also the relative costs of the various R&D approaches. For example, reliance on mature components kept R&D costs for the M-247 unusually low, while costs for the AGM-86B development were particularly high because it included a considerable number of prototype and pilot production missiles. Also, these ratios should be viewed with some caution because they are based on uncertain estimates of UPC growth in the absence of competition. For example, a 95 percent confidence interval would permit estimates of the median UPC growth rate for the noncompetitive programs to vary from 2.9 to 9.1 percent, as opposed to the 5.8 percent assumed above. If 2.9 percent was the median noncompetitive UPC growth rate, the savings/cost ratio would be one or greater only for the M-247 competition.

3. At What Point within the R&D Phase Does It Appear from These Data That Competition Should Be Terminated?

The overriding concern should be to carry competition far enough that the development contractors can prudently propose production options with competitively determined price ceilings. At a minimum, this means that fully integrated prototype systems should be tested and that considerable attention should be paid to producibility and production planning. If competition is carried further, contractor risks may be reduced so that the Government can require the price ceilings to be more comprehensive in terms of the procurement cost categories covered as well as the production quantities and the number of years included.

Paper proposals alone do not provide an adequate basis on which to determine which design would cost less to produce. Three of the case studies (i.e., the AH-64, the M-247 and the AGM-86B) included major cost-reducing innovations that were originally controversial and that were accepted by the Government only after they were demonstrated during prototype testing. Further, while a requirement for competitively priced production options does not appear to be necessary to motivate competitors to build potential cost-saving features into their designs during the competitive phase, such firm price commitments do seem to increase the intensity of that effort and, more importantly, provide the winning contractor with a continuing motivation to realize those potential savings through cost control during follow-on, sole-source, design maturation and production phases. The M-1 Program demonstrated that it is feasible to require priced production options after an advanced-development (AD) competition, even though production will not be initiated for two and one-half years. But if competition is carried through full-scale engineering development (FSED), as was the case for the M-247 and the AGM-86B (production was initiated one year following the M-247 competition and immediately following the AGM-86B competition), then the competitively determined price commitments can be much more comprehensive since the competitors are in a much better position to estimate their production costs.

4. What Economic Criteria Would Assist in Judging the Desirability of R&D Competition for Particular Systems?

In evaluating whether a new development program should include prototype competition as a tool to reduce procurement costs, the potential savings should be compared with the incremental costs of staging a well-structured competition. If the potential savings are not greater than the incremental costs on a constant-dollar, discounted basis, then competition should not be employed.

The incremental cost of competition should be estimated based on a development strategy that would permit a well-structured competition, including competitively priced production options, for the particular program under consideration. The estimated savings should similarly be based on characteristics peculiar to the candidate program, especially those characteristics affecting the risk of cost growth and the opportunity for competition to control such growth. The conditions to be considered should include:

- Technical risk,
- Component maturity,
- Schedule concurrency,
- Program stability,
- Requirements stability,
- Company characteristics.

In summary, then, the data in this study indicate that prototype competition is a valuable tool for the control of procurement costs. There are other tools, prototype competition may be too costly for some programs, and expected savings will not be realized each time competition is used. For many programs, however, a well-structured prototype competition has the potential to pay for itself through procurement cost savings. And a substantial bonus may well be available by way of improved performance, reduced schedule risk, and lower operating and support costs.

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CHAPTER I

INTRODUCTION

This study explores the use of prototype competition during the R&D phase of major weapon acquisition programs as a tool to control eventual procurement costs. The research was performed for the Office of the Deputy Under Secretary of Defense (Acquisition Management) under contract number MDA 903 79 C 0018. The tasking of this study, in part, reflects DoD's emphasis on enhancing the use of competition as part of the current Acquisition Improvement Program (AIP). In addition, a number of acquisition programs that initiated R&D prototype competitions during the 1970s have now progressed to the point that procurement cost impacts can be assessed. The study is undertaken from an economic perspective and addresses four principal questions:

- Does prototype competition during the R&D phase result in lower production costs?
- Do these downstream savings compensate adequately for the incremental, up-front costs of using competition?
- At what point within the R&D phase does it appear from these data that competition should be terminated?
- What economic criteria would assist in judging the desirability of R&D competition for particular systems?

The study recognizes but does not attempt to measure such other potential benefits of competition as improved performance, lower schedule risk and reduced operations and maintenance costs. Nor does the study dwell on the use of competition during the production phase of acquisition.

R&D prototype competition has been utilized for defense procurement to some extent since at least 1820. Reliance on such competition increased during the 1970s as a result of the initiatives of Deputy Secretary of Defense David Packard. Previous studies have provided tentative evidence that the use of prototype competition can reduce procurement cost growth.[1]

The approach of the present study was to analyze a broad sample of acquisition programs using readily available data to determine whether programs that included R&D prototype competition did indeed exhibit better procurement cost results than programs without such competition. Following that analysis, case studies were conducted for four specific programs that included R&D prototype competition, in order to explore how competition achieves its results and verify that any favorable procurement cost results were indeed attributable to competition. The programs studied included:

- AH-64 Apache Attack Helicopter System,
- M-1 Abrams Tank System,
- M-247 Sgt. York Air Defense Gun System, and
- AGM-86B Air-Launched Cruise Missile.

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[1]The major empirical studies are: G.K. Smith et al., "The Use of Prototypes in Weapon System Development"; and Edmund Dews et al., "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s." Other relevant analyses include: G.R. Hall and R.E. Johnson, "Competition in the Procurement of Military Hard Goods"; James A. Evans, "Potential Adverse Effects of Competitive Prototype Validation"; B.H. Klein et al., "The Role of Prototypes in Development"; and Clarence A. Patnode, Jr., "Problems of Managing Competitive Prototype Programs."

The case studies were based on the available literature as well as visits to the respective Army and Air Force project management offices (PMOs) and the winning contractors.[1]

This report is organized into chapters as follows:

- Chapter II: Rationale for Expecting R&D Prototype Competition to Control Unit Procurement Cost,
- Chapter III: Comparison of Cost Growth Data for Major Systems,
- Chapter IV: Summary of Four Case Studies of R&D Prototype Competition,
- Chapter V: Analysis of R&D Prototype Competition, and
- Chapter VI: Conclusions.

Chapter II explains how R&D prototype competition could lead to lower eventual procurement costs, and discusses the dependence of such a result on how a competitive program is structured. Chapter III compares procurement cost growth for samples of acquisition programs that did or did not include prototype competition. Chapter IV summarizes and compares case studies of four particular competitive programs. (Detailed reports on the case studies themselves are presented as appendices to the main report.) Chapter V specifically addresses the four questions stated in this Introduction, based on what was learned from the sample comparisons and the case studies. Chapter VI presents concluding remarks.

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[1]Nevertheless, the opinions expressed in this report are those of the author and are not necessarily endorsed by the officials contacted.

CHAPTER II

RATIONALE FOR EXPECTING R&D PROTOTYPE COMPETITION TO CONTROL UNIT PROCUREMENT COST

This chapter reviews the argument that R&D prototype competition can lead to lower unit costs in procurement. It also discusses the dependence of such a result on the way in which a competitive program is structured.[1]

A. DETERMINATION OF UNIT PROCUREMENT COST

For purposes of this discussion, the unit procurement cost (UPC) of a new weapon system depends importantly on:

- Determination of user requirements to be satisfied,
- Design of the system, and
- Transition of the design into production.

To some degree, a weapon system's UPC is determined when its required capabilities are defined by the prospective user. No matter how efficient the subsequent development program is, there is some (implicit) minimum UPC needed to provide those capabilities. How the system is designed, however, will have a strong impact on how close the eventual UPC is to realizing this minimum level. In fact, the design process may even change the minimum achievable UPC level if user requirements are sufficiently flexible to adjust to what is learned in the

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[1] For a wide-ranging discussion of the problem of cost growth in defense acquisition, see American Defense Preparedness Association, "Report of the Chicago Cost Discipline Conference."

design process about costs. That is, various capabilities will turn out to be more expensive or less expensive than originally anticipated so that the best mix of capabilities to achieve the user's mission may change from what was first believed.

Even if trade-offs between cost and performance features are not made, the eventual UPC will depend greatly on the importance placed on production costs during the design effort. UPC can be controlled at the design stage by identifying the cost implications of design decisions and taking care to choose the least-cost way of performing each task. To some extent, cost control is a scrubbing process to ensure that new components are not designed, and existing components are not selected, that are more capable and costly than needed. It may be a matter of designing parts so as to avoid costly materials or shapes that are difficult to produce. Considerable creativity may be required to devise less costly ways of achieving the user's stated requirements.

Inherent in the emerging system design is its own minimum UPC, namely the lowest unit cost of producing the design achievable using efficient production methods. Reaching this minimum UPC is not at all assured; it depends on the continuing importance attached to production costs as the design transitions into production. The transition stage requires many design changes to improve the system's producibility (now that the design is relatively mature from a performance point of view). Production methods must be established, production and test equipment selected, plant layouts planned, and investment decisions made. As production begins, workers and managers must be motivated to achieve potential "learning curve" reductions in unit costs through a continuing series of adjustments in production methods and producibility design. Thus, the eventual UPC depends on a succession of decisions as requirements are defined and the system is designed and transitioned into production.

B. SOLE-SOURCE CONTROL OF UNIT PROCUREMENT COST

In a sole-source environment, the development contractor may have relatively little motivation to control eventual UPC. One potentially important motivator is the affordability of the program. There may be some level of UPC at which the program would become so expensive that it would be severely reduced or terminated for budgetary reasons by the affected Service, OSD or the Congress. That level is probably far above the minimum achievable UPC level, particularly for development programs with high priority. On the other hand, there are several reasons why a firm might be indifferent to cost control or even favor actions leading to higher costs. Most importantly, contractor profits are ultimately based on contract costs; that is, even under a fixed-price contract, the Government negotiates the price to include a profit calculated as a fairly standard percentage of reasonable costs. Thus, a more costly system may enable the contractor to negotiate a higher profit, assuming the system costs can be defended as reasonable.[1]

Contractors have an interest in using a present contract to give them advantages for future programs or their commercial markets, thus the contractors may prefer to utilize advanced technologies in order to build up their technological

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[1]As exemplified in Appendix A, Government negotiators do challenge the costs proposed by contractor negotiators, but little can be done during production negotiations about costs already built into a system's design.

capabilities, even if that increases UPC. Similarly, the contractors may unnecessarily raise UPC through excessive investment in plant and equipment, to be amortized during the present development program and then utilized for other purposes. Similarly, the contractors may produce components themselves that could be produced more efficiently by subcontractors. In addition, unit cost control is not free to the contractor and may require an allocation of internal resources for that purpose, including its better management and engineering talent and its more efficient production facilities. The contractor is unlikely to dedicate its best resources to a sole-source development program for the Government if they are also needed for its competitive commercial market. Thus, the sole-source contractor has a number of reasons to be indifferent or antagonistic toward a Government preference for lower UPC, in addition to the contractor's fundamental desire to maximize profit over and above UPC.

In a sole-source development program, the Government controls UPC administratively and, to some extent, through incentive fees. Undoubtedly these efforts do some good.[1] The effectiveness of administrative controls is limited, however, because the Government does not have the data or personnel to second-guess all of the contractor's decisions (i.e., design the system for the contractor). Further, estimates of UPC or of the cost impact of a particular engineering change are so uncertain prior to production that the Government (or indeed the contractor) may be unaware of UPC problems as they develop. The Government's own internal organization motivates

[1]Under its current Acquisition Improvement Program, DoD is making a concerted effort to improve its administration of the acquisition process.

both contractors and Service program management offices (PMOs) to be optimistic in their UPC estimates in order to compete for funding with other programs, making it even more difficult to identify and deal with UPC problems. In addition, the Government's effective commitment to UPC control for a particular program is likely to vary over time as personnel and budgets change. Incentive fees for the achievement of UPC goals during development programs may be useful if the fees are large enough to outweigh the contractor's other motivations. However, the size of incentive fee needed to motivate a sole-source contractor may be substantial.

C. COMPETITIVE CONTROL OF UNIT PROCUREMENT COST

1. Introduction

This study is concerned with the impact of R&D prototype competition on unit procurement cost (UPC). R&D prototype competition means the funding of parallel development programs for a weapon system, including the design, fabrication and testing of prototype systems to meet a common set of requirements with the intent of choosing only one of the designs for further development and/or production.[1] Thus, R&D competition as used here does not include paper competitions or parallel study contracts. The hypothesis to be explored in the present study is that R&D competition, if it is properly structured, can have a major impact on eventual UPC. Since the awarding of follow-on development and/or production contracts would depend on what contractors did during a competitive phase, R&D competition can give the Government tremendous leverage over development contractors. While this

[1]Competition might be reintroduced during the production phase.

study concentrates on the use of that leverage to motivate the competitors to control UPC, it can also be used to obtain better technical performance, more certain program schedules, and lower operations and support costs. The emphasis and the results would depend on how the competitive program was structured.

Competition works because a contractor must assume that its opponent will do everything possible to design a system that meets the Government's expectations. A contractor will be awarded the follow-on contract only if it can somehow do a better job than its opponent. Thus competition can motivate a contractor to assign its best management, engineering and production resources to the development effort. Perhaps more importantly, competition can motivate a contractor to pay attention to what the Government considers to be important. In a well-structured competition it is in the contractor's best interest to do what is in the Government's best interest.

2. Competitive Incentives to Control Unit Procurement Cost

If competitive development contractors are to be motivated to control eventual UPC, they must be convinced that such control is essential to their chances of being awarded the follow-on contracts and profiting from them. In this study, the following factors are assumed to be essential to inducing that belief:

- Value of winning,
- Credibility of competitors,
- Importance of cost to the source selection,
- Validation of cost estimates,
- Priced production options,
- Competition during production, and
- Correction of design deficiencies.

Whether these factors can be structured so that prototype competition makes sense for a particular program will depend to a great extent on the objectives and characteristics of the program and of the potential contractors.

a. Value of Winning

The potential value of the follow-on contracts must be sufficient such that the competitors will try hard to win them. Their value includes potential profits from the contracts themselves together with the potential for foreign military sales (FMS), commercial spin-offs, or strengthening of the firm's technological capabilities. The point of competition, from the Government's point of view, is to exploit each contractor's desire to win.

b. Credibility of Competitors

It is also important that the competitors be well-matched so that they will take each other's chances of winning seriously and hence try hard themselves. There is nothing wrong with having an underdog so long as it has a credible chance of winning, but if one of the contractors should fail to develop a working prototype in time for comparative testing at the end of the competition, or should deliver a clearly inferior product, then the other competitor will feel no pressure in preparing its cost proposal for the follow-on phase. A worse situation is one in which one of the competitors is convinced from the start that it will win--in this instance, competition will have little or no impact on its design effort.

c. Importance of Cost to the Source Selection

In order for the R&D competition to have much impact on eventual UPC, the competitors must believe that UPC will play a major role in the source selection for the follow-on phase. Thus, UPC should be accorded a high priority among the published criteria that will govern the source selection. A competitive program cannot be expected to impact UPC if that is not a principal Government objective, although competition might still be worth pursuing to achieve other objectives.

d. Validation of Cost Estimates

The Government must be able to identify what unit cost differences exist between the competing designs. There would be little point in a competitor making a serious effort to control UPC if an optimistic cost estimate could serve the same purpose. Also, the Government might throw away the best design (from a UPC standpoint) if it could not discern truth from fiction. This is why prototype competition has such an advantage over paper competition. In the prototype competition, the contractor must demonstrate that its design does what it is supposed to do. In the process, the contractor identifies the need for changes in its original design concept in order to achieve the required performance, and those changes affect UPC. Thus, the development, testing and modification of the prototypes allow the cost estimators to base their UPC estimates on designs that are much closer to the eventual production designs than the designs that were included in the initial paper proposals. In addition, the prototypes provide detailed experience with parts design and fabrication (although volume production methods may not be used) and with the acquisition of materials and components from other vendors. This experience permits better "bottoms up," part-by-part estimates of eventual UPC.

e. Priced Production Options

Before the competition ends, the contractors should be required to submit proposals for firm ceiling prices for multiple production options to be exercised during the follow-on phase. This requirement is really the keystone to a successful effort to reduce UPC through R&D competition. If the competitors know from the beginning that their profits will depend on their ability to produce their designs at the unit costs that they estimate, then they will be forced to be very realistic about their estimates. This, in turn, will motivate them to take steps that really control UPC during the design phase rather than merely trying to develop credibly low UPC estimates. In this context, the value of the prototypes is that they give the contractors sufficient information so that they can prudently propose firm price ceilings. The price ceilings aid the Government in validating the UPC estimates but do not replace them, since it is still necessary (in selecting between the proposals) to estimate what costs will be after the competitively priced options have been exercised.

The competitors will be under great pressure to keep their ceiling price proposals low, and hence can be expected to sacrifice some profits in their bids. The ceiling prices will force the contractors to continue efforts to control UPC during the sole-source, follow-on phase (including any required design maturation effort, producibility engineering and production planning) as well as during production itself. Thus, priced production options have the effect of extending the motivation of competition into the sole-source phase. The ceilings can even help to control UPC for production years after the competitively priced options have been exercised. That is, by the time the Government must negotiate procurement prices for those later (probably sole-source) years, it will have some information on actual production costs for the initial years of production. Thus, the competitively determined option prices will motivate the contractors to achieve efficient production during the years covered, and the Government's negotiating position for later years can be based on the learning curve thus demonstrated. While a negotiating position is not a price, the information should result in lower prices than would otherwise be negotiated.[1] Thus, firm ceiling prices for production options can be expected to reinforce the motivation to control UPC during the design phase, to extend that motivation through the transition-to-production phase (even if that phase is sole-source), and to aid the Government in negotiating procurement prices even after the options have all been exercised.

f. Competition during Production

The possibility of reintroducing competition during the production phase should be kept open. This could even include a leader/follower or teaming arrangement to established dual production sources from the start. At a minimum, a complete technical data package should be required to be available in time to compete the award of the first production contract

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[1]Increasing the number of years included in the priced production options will tend to reinforce the motivations discussed in this section. But at some point, the contractors' risks would become so great that they would either refuse to bid or would bid so conservatively that the Government's savings would be reduced. Similarly, including a broader cross section of the hardware items to be procured under the ceilings would increase the value of the ceilings to the Government and the risks to the contractors.

beyond the competitively priced production options. The threat of follow-on production competition is important because it may discourage an R&D competitor from bidding below cost for the production options in the expectation of recouping its losses during the sole-source follow-on phase (i.e., buying in). In turn, this should increase the contractor's motivation actually to control UPC during the design and production phases.

g. Correction of Design Deficiencies

The competitors should be required to accept responsibility for correcting design deficiencies that prevent the product from meeting its performance and reliability specifications. By including the cost of this provision in the production option ceiling prices, the Government can better control this aspect of UPC. In addition, this provision would offset any tendency for the pressure to control UPC to result in increased design risks.

h. Observation on Incentive Factors

As noted above, factors such as these determine whether competitive contractors will indeed be motivated to control eventual procurement costs. If conditions will not permit a competition to be structured so as to induce the desired contractor response, then competition would be a waste of money (from the viewpoint of controlling procurement costs). To some extent, the Government can control what incentives result from the competitive program, but that will also depend on the peculiar characteristics of the available contractors, the relevant technologies, and the mission requirements.

CHAPTER III

COMPARISON OF COST GROWTH DATA FOR MAJOR SYSTEMS

This chapter analyzes unit procurement cost growth for a sample of major acquisition programs, using data from the Selected Acquisition Reports (SARs).[1] Those programs that included prototype competition during their R&D phases experienced a lower rate of cost growth than the remaining systems in the sample, suggesting that R&D competition can indeed lead to lower unit procurement costs.

A. COST GROWTH AS A MEASURE OF COMPETITIVE SAVINGS

The success of an acquisition program's efforts to control procurement costs should be measured by comparing eventual procurement costs with the minimum level that could have been achieved. While that minimum level is unknown, the Services do estimate what they expect eventual procurement costs to be when a new program is approved for full-scale engineering development (FSED). This is the so-called development estimate (DE) reported in the SARs.[2] The DE of eventual procurement costs provides a plausible cost standard because it is made at a time when user requirements and technical concepts are considered to be sufficiently mature

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[1]See Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

[2]The DE is based on parametric studies and other available information.

that the system can be designed and tested for production.[1] The DE attempts to predict what procurement costs will eventually be, although that remains highly uncertain. Since the DE provides an indicator of (and must be consistent with) future funding requirements, proponents of a program have an incentive to be optimistic in formulating the DE, in order to improve the program's chances of being funded for FSED. Thus, the DE is also something in the nature of a goal; comparing a current estimate (CE) of procurement costs with the DE provides a reasonable indicator of how effectively an acquisition program has controlled procurement costs.

If prototype competition does actually lead to better control of eventual procurement costs, then cost growth (measured from the DE to a CE) should be lower for programs with than for those without prototype competition. This is clearly the case when competition occurred during the FSED phase. But what of those programs where prototype competition occurred during advanced development (AD), before the DE was formulated? In such cases, it can be expected that the DE itself was affected by the competition. On the one hand, the development and testing of prototypes should enable the developing Service to make a more realistic DE. On the other hand, the revelation of cost problems during prototype development could be expected to force the competitors to identify cost-reducing solutions. While it is possible that

[1]An earlier procurement cost estimate would be much more uncertain and to some degree unrepresentative. A later estimate would tend to reflect the actual system design and would not provide much of a standard with which to evaluate that design.

prototype realism could lead to a higher DE[1], this seems unlikely in light of the offsetting competitive motivations. The evidence on this point (discussed in Section C below), though not conclusive, does not indicate a tendency for competition to raise the DE.

Besides improving the realism of the DE, why would an AD prototype competition lead to lower growth in estimated procurement costs during a follow-on, sole-source, FSED phase? Potential sources of lower growth include:

- the Government's improved ability to select a design for FSED that will experience lower cost growth, and
- the winning contractor's continuing motivation to control cost growth if competitively priced production options are established.

The Government's ability to select a design approach for FSED improves because it is able to choose between two (or more) approaches that have been demonstrated through prototype fabrication and testing, rather than basing its choice largely on studies and contractor claims. The prototype experience aids the Government in identifying which approach is subject to greater risks of technical problems and cost growth. Further, identified problems can be resolved early in an innovative, competitive environment rather than later in an environment that is less flexible and sole-source. The contractors may also be motivated to avoid undue technical risks in their design approaches in order to assure that their prototypes will be ready in time for the competitive testing.

If the AD competition ended with competitively priced production options, to be exercised after a sole-source FSED

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[1]See, for example, G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 18.

phase, then the winning competitor would have a compelling reason to control cost growth during the follow-on phases. This could lead to better cost control during the critical FSED producibility design and production planning efforts as well as during the execution of the production options. In addition, since major Government-directed design changes could invalidate the favorable option prices, the Government might be motivated to restrict its requirements changes.

In summary, then, acquisition programs that included R&D prototype competition should be expected to exhibit lower growth in estimated procurement costs (compared to programs without prototype competition), measured from the development estimate (DE) of procurement costs at the beginning of full-scale engineering development (FSED). Lower cost growth should be expected whether the competition occurred before or after the DE was made, although measuring cost growth from the DE will not reflect the impact AD competition might have had in lowering the DE itself (from what it otherwise would have been).

B. EXPLANATION OF DATA

The data for the following comparisons of growth in procurement cost estimates are drawn from the Selected Acquisition Reports (SARs) of December 1982. The SARs are prepared by the Service program management offices (PMOs) to report cost and performance data for selected systems to OSD and Congress.[1] While the number of acquisition programs required to prepare SARs is now being increased, previous criteria applied the SAR requirement principally to systems

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[1]See DoD Instruction 7000.3.

that had been approved for full-scale engineering development (FSED) by passing Milestone II of the DSARC process and that met certain minimum cost thresholds.

This analysis compares the development estimates (DEs) made at the beginning of FSED with the current estimates (CEs) of unit procurement cost (UPC) reported in the December 1982 SARs. UPC is a broad measure that includes manufacturing costs for the system itself and for training and peculiar support equipment, initial spares and repair parts, as well as costs for certain activities in support of production.[1] UPC does not include costs for research and development, military construction, or operations and maintenance. UPC is calculated by dividing projected procurement costs over the life of the program by the quantity of systems to be procured. The SARs present UPC estimates in escalated dollars (reflecting historical and expected future inflation) as well as in constant dollars (stating historical and future costs in terms of the value of a dollar in the base year of the particular program). This analysis uses the constant-dollar estimates so that inflation will not distort comparisons among programs whose DEs were established at different times. The measure of UPC growth used is the average annual percentage change in UPC for each program.

The sample to be analyzed includes the 41 programs submitting SARs in December 1982 for which the DE had been

[1]See DoD Instruction 5000.33 for a precise definition. Unit costs are used to reduce distortions due to changes in procurement quantities.

made at least three years earlier.[1] Identification of those programs that included R&D prototype competition was based on a 1981 survey of competition in acquisition programs by OSD.

C. COMPARISON OF COST GROWTH RATES

1. Cost Growth Rates

The 14 competitive and 27 noncompetitive sample programs are identified in Table 1, which also indicates each program's average annual percentage change in unit procurement cost (UPC) since its development estimate (DE) was made. The median annual UPC growth rate is 3.1 percent for the competitive sample and 5.8 percent for the noncompetitive sample.[2] This comparison is based on the median (i.e., the value for each sample with half of the growth rates above it and half of the growth rates below it) in order to avoid misleading distortions caused by extreme sample values when the mean is used.[3]

The data thus suggest that a difference exists between the median UPC growth rates of competitive and noncompetitive

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[1] Eleven SAR systems were thereby eliminated from the sample because their DEs were too recent to permit meaningful cost growth estimates.

[2] In Edmund Dews et al., "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s," p. 28, it was reported that mean program costs had increased less (relative to the DEs) for four programs with prototype competition than for six programs without prototype competition.

[3] The mean rate of growth is 8.8 percent for the competitive programs, compared to 7.3 percent for the remaining programs. But if the Copperhead is removed from the competitive sample and the LAMPS Ship and CAPTOR are removed from the noncompetitive sample, the comparison of means is 4.4 percent for the competitive sample and 6.0 percent for the noncompetitive sample. The cost growth for the Copperhead was severely affected by a 13 to 1 reduction in the quantity of projectiles to be procured.

Table 1. GROWTH IN UNIT PROCUREMENT COST BY SYSTEM

PROGRAMS WITH R&D PROTOTYPE COMPETITION		PROGRAMS WITHOUT R&D PROTOTYPE COMPETITION			
PROGRAM	ANNUAL PERCENT CHANGE*	PROGRAM	ANNUAL PERCENT CHANGE*	PROGRAM	ANNUAL PERCENT CHANGE*
MLRS	-2.3	Sidewinder	-1.5	Stinger	6.4
DIVAD	-0.3	AV8B	-0.5	HARPOON	6.4
F/A-18	1.5	NAVSTAR	0.4	FFG-7	7.5
AN/TTC-39	1.8	Trident Missile	0.7	DSCS 3	7.7
UH-60A	2.0	SSN688	0.8	TACTAS	9.1
SLCM	2.2	CG-47	1.4	HARM	9.9
E-3A	2.8	F-15	2.6	Patriot	10.2
F-16	3.4	Trident Submarine	2.6	LAMPS Aircraft	11.8
M-1	5.7	F-14A	2.9	EF-111A	13.6
Hellfire	7.1	IR Maverick	3.3	Bradley FVS	13.6
ALCM	8.5	CH-47D	3.5	Pershing 2	22.2
AH-64	9.9	CH-53E	4.3	LAMPS Ship	22.4
GLCM	15.3	Phoenix	5.1	CAPTOR	25.8
Copperhead	66.0	Sparrow	5.8		

*Average annual percentage change in constant-dollar unit procurement cost (UPC) from time of development estimate (DE) until December 1982. Based on information in Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is unclassified.

programs. Nevertheless, the amount of this difference cannot be estimated with precision. For these particular samples, the median annual UPC growth rate for noncompetitive programs exceeds that for competitive programs by 2.7 percent. Yet the data indicate that, at a 95 percent level of confidence, the estimate of the true median for noncompetitive programs can be narrowed only to a range of from 2.2 percent below to 5.0 percent above the median for competitive programs. At a 77 percent level of confidence, the true median for noncompetitive programs can be estimated to be greater than that for competitive programs. And at a 50 percent level of confidence, the noncompetitive median can be estimated to be at least 1.1 percent greater than the competitive median.[1]

A precise estimate of the difference in median UPC growth rates cannot be made due to the small sample sizes and the considerable variation among individual UPC growth rates due to factors other than prototype competition. In addition, the programs that did utilize prototype competition vary among themselves with regard to how well their respective competitions were structured.[2]

2. Sample Characteristics

Is the use of prototype competition responsible for the difference in median UPC growth rates discussed in Section 1? This section analyzes whether the difference might,

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[1]These confidence limits were derived based on the Wilcoxon rank-sum test and assume that the probability distributions for the competitive and noncompetitive populations have identical shapes and variances. See James V. Bradley, "Distribution-Free Statistical Tests," p. 114.

[2]See the discussion in Chapter II, Section C.

instead, be due to certain other characteristics of the competitive and noncompetitive samples.

As indicated on Table 2, the distributions of the competitive and noncompetitive samples by type of weapon system are roughly equivalent, with both samples including a broad range of types. The median UPC growth rate is lower in the competitive sample for three out of the four weapon types represented in that sample. Thus, the lower growth rate for the competitive sample is not due to the particular mixes of weapons included in the two samples. In fact, the major discrepancy in weapon types, namely that ships are included only in the noncompetitive sample, makes the competitive sample look worse in the comparison of overall sample medians. If ships are excluded, the comparison of medians is 3.1 percent for the competitive sample and 6.1 percent for the noncompetitive sample.[1]

A large discrepancy in sample ages could distort the comparison of UPC growth rates, but in fact (as indicated on Table 3) the median number of years since the DEs were made is quite close, being 6.5 years for the competitive sample and seven years for the noncompetitive sample.[2] An adjustment for this effect can be made by calculating the annual rate of UPC growth only to the point where a system reached IOC, for the

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[1]In fact, a good case could be made for excluding ships from the comparison. Development estimates (DEs) for ship programs frequently are not made until the designs are largely complete and they are approaching the DSARC 3 production decision. Thus, much of the cost growth measured in other programs may already be reflected in the DE estimates for ships.

[2]An age discrepancy could distort the comparison since UPC tends to grow at a slower rate after a system reaches its initial operational capability (IOC), as reported in Norman J. Asher and Theodore F. Maggelet, "On Estimating the Cost Growth of Weapon Systems," page 28.

Table 2. COMPOSITION OF SAMPLES BY WEAPON TYPE

PROGRAMS WITH R&D PROTOTYPE COMPETITION			PROGRAMS WITHOUT R&D PROTOTYPE COMPETITION		
WEAPON TYPE	PERCENT OF SAMPLE	MEDIAN UPC PERCENT CHANGE*	WEAPON TYPE	PERCENT OF SAMPLE	MEDIAN UPC PERCENT CHANGE*
Aircraft	28.5	2.7	Aircraft	22.2	3.2
Missiles	28.5	7.8	Missiles	37.0	6.1
Other Electronics	14.5	2.3	Other Electronics	14.8	8.4
Ships	0	—	Ships	18.5	2.6
Ground & Other Systems	28.5	2.7	Ground & Other Systems	7.5	19.7

*Median annual percentage change in constant-dollar unit procurement cost (UPC) from time of development estimate (DE) to December 1982. Based on information in Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

Table 3. COMPARISON OF SAMPLE CHARACTERISTICS

Characteristic	Programs With R&D Prototype Competition	Programs Without R&D Prototype Competition
Number of Programs	14	27
Median Age (Years From DE to December 1982)	6.5	7
Median Size (Estimated Procurement Cost at DE in Billions of Base Year Dollars)	$1.487	$0.616
Median Change in Procurement Quantity (From DE to December 1982)	1.2%	0%
Median Annual UPC Growth Due to Engineering Changes (From DE to December 1982)	.4%	.6%
Percentage of Programs With Design-to-Cost Reporting	57.1%	51.9%

17 sample programs that had reached IOC by December 1982. On this basis, the median annual growth in UPC was 2.5 percent for the competitive sample and 5.8 percent for the noncompetitive sample.

The discrepancy in the median size of the procurement programs in the two samples, however, is substantial, being $1.487 billion (in constant dollars at the time of the DE) for the competitive sample versus $0.616 billion for the noncompetitive sample. On the one hand, it may be more difficult to control cost growth in larger programs; on the other hand, larger programs may receive more management attention at the Service, OSD, and Congressional levels. The net effect of this size discrepancy is unclear.

Changes in the quantity of systems to be procured under a particular program (from the quantity planned at the time of the DE) could have a substantial impact on UPC growth. A quantity increase would tend to reduce UPC by permitting greater learning and enabling fixed costs to be spread over more units. A quantity decrease would tend to have an opposite effect. Accordingly, a discrepancy in quantity changes between the competitive and noncompetitive samples could lead to a difference in median growth rates.[1] In fact, however, the quantity changes experienced by the two samples are quite similar, with a median quantity change of 1.2 percent for the competitive programs and zero percent for the

[1]Quantity changes may be imposed on a particular program due to changes in mission requirements or in the Service or DoD budget. In some cases, however, quantity changes result from cost or technical performance within the particular programs affected.

noncompetitive programs.[1] Thus, while quantity changes affected UPC growth for individual programs, such changes do not explain the difference in median UPC growth rates for the two samples.[2]

Another potentially important determinant of cost growth is the need for design changes necessitated by Service-imposed changes in system requirements. If system requirements were more stable for competitive programs, that would tend to lower their median UPC growth rate. The SAR data, however, indicate that median annual UPC growth due to engineering changes amounted to 0.4 percent for competitive programs and 0.6 percent for noncompetitive programs.[3] This discrepancy is too small to account for the difference in median UPC growth rates.

The discussion in Section A above raised the possibility that prototype competition prior to the DE might tend to raise the level of the DE since cost estimates based on the

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[1]The mean quantity changes were 40.6 percent for the competitive programs and 52.4 percent for the noncompetitive programs.

[2]The SAR data do not permit a satisfactory estimate of what UPC growth would have been without quantity changes. While the SAR does report cost changes due to quantity changes, this allocation is supposed to be based on the original cost/quantity relationship as of the time of the DE. Hence, this allocation should not reflect subsequent cost growth and can be expected to understate the (constant-dollar) cost of procuring the units involved in the quantity change. (Instructions for making the quantity allocation are specified in DoD Instruction 7000.3.)

[3]This comparison should be viewed with caution due to possible inconsistencies among the various programs as to what was treated as an engineering change. In some cases, this category includes design changes necessary to achieve unchanged requirements, as well as those resulting from new requirements. While this data suggests a similarity in the experience of competitive and noncompetitive programs, it cannot be used to estimate the cost impact of all engineering changes.

prototypes would be more realistic. If this were true, it would suggest that a lower UPC growth rate following the DE would not represent true cost savings.[1] The evidence on this point is sparse. Nevertheless, the SARs do include data for some programs on the growth of unit program acquisition costs (including R&D, procurement, and military construction costs in escalated dollars) from the planning estimates (PEs) at the inception of the programs until the DEs. The median annual percentage change in this measure was 15.0 percent for three competitive programs and 19.1 percent for nine noncompetitive programs.[2] Further, the three competitive programs that did not test prototypes prior to their DEs (namely the MLRS, the DIVAD, and the UH-60A) were among the five competitive programs with the lowest UPC growth rates (from their DEs). Also, two of the case study programs summarized in Chapter IV, namely the AH-64 and the M-1, included prototype competition prior to formulation of their DEs. The DE's for unit hardware costs for the two programs were less than or equal to the estimates made prior to their respective competitions. Thus, the data provide no indication that prototype competition tends to raise the level of a competitive program's development estimate (DE) of procurement costs. While the DEs for the competitive programs are more realistic, the data suggest that prototype competition can improve cost control both during and after the competitive phase.

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[1]Eleven of the 14 competitive programs tested prototypes prior to calculating their DEs. Many of the noncompetitive programs also included some full-scale hardware testing prior to their DEs. See Edmund Dews _et al._, "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s," page 17.

[2]These are the programs for which distinct planning estimates (PEs) were available and were made at least two years prior to the DEs.

Design-to-cost (DTC) efforts provide another potential mechanism for controlling UPC.[1] Under DTC, specific cost goals are established early in the program. These goals are supposed to be treated as design parameters and to lead to cost control during the design effort, including trade-offs with other program objectives as necessary to achieve the DTC goals. In some cases, incentive fees are awarded to contractors for DTC achievements. In other cases, the DTC goal is primarily a management threshold for the PMO. For the eight competitive programs that reported DTC goals and estimates following their DEs, the median annual UPC growth was 4.0 percent. For the 14 noncompetitive programs with DTC, median UPC growth was 7.0 percent.[2] Thus, the discrepancy in UPC growth rates persists even among programs with DTC goals. Nevertheless, discussions in following chapters will indicate that DTC can be a very effective tool in a well-structured competitive program.[3]

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[1]Formal DTC efforts were initiated by DoD in the early 1970s and are defined in DoD Directive 4245.3.

[2]DTC goals typically exclude some costs included in UPC, such as initial spares and repair parts and peculiar support equipment. On the more narrow DTC basis, the median growth rates for unit costs were 4.5 percent for the competitive programs and 6.4 percent for the noncompetitive programs.

[3]When DTC incentives are used, they usually amount to no more than three or four percent of the R&D contract target cost. In a competitive program, however, the incentive to achieve a DTC goal is much greater, namely the value to the contractor of the follow-on development and production contracts.

3. Summary of Cost Growth Comparison

The comparison of UPC growth rates suggests, but does not prove, that the use of prototype competition can lead to lower UPC growth than would occur without competition. The median UPC growth rate is lower in the competitive than in the noncompetitive sample of programs, although small sample sizes and the variability of the data prevent a precise estimate of the amount by which the true medians differ.[1] Further, an examination of cost-related characteristics of the two samples indicates that differences in those characteristics are not sufficient to explain the difference in median UPC growth rates.[2] Accordingly, the lower median UPC growth rate for competitive programs can plausibly be attributed to the use of prototype competition.

[1] Indeed, at a 95 percent level of confidence, the possibility that the true medians are the same cannot be rejected.

[2] This analysis was limited to characteristics for which appropriate SAR data was readily available. Thus, some important characteristics, such as changes in production rates, were not explicitly addressed.

CHAPTER IV

SUMMARY OF FOUR CASE STUDIES OF R&D PROTOTYPE COMPETITION

In order to assess whether R&D prototype competition can indeed lead to lower unit procurement cost (UPC), this study has analyzed four of the competitive programs further. These are:

- AH-64 Apache Attack Helicopter System,
- M-1 Abrams Tank System,
- M-247 Sgt. York Air Defense Gun System,
- AGM-86B Air-Launched Cruise Missile.

The AH-64 advanced development (AD) competition was followed by an extended period of sole-source, full-scale engineering development (FSED) and did not result in competitively priced options for future production. The M-1 AD competition also was followed by an extended sole-source FSED phase, but did provide for production options with competitively determined ceilings for recurring production costs. The Sgt. York Program omitted the usual advanced development (AD) phase and instead began with a FSED prototype competition, followed by a relatively short sole-source design maturation phase and providing for production options with comprehensive, competitively determined ceiling prices. The ALCM Program included a sole-source AD phase and a competitive follow-on phase requiring the design and testing of FSED prototypes as well as the initiation of pilot production, and also provided for production options with comprehensive, competitively determined ceiling prices. Accordingly, these programs encompassed a successively more complete variety of competitive approaches.

The four case studies are based on Congressional testimony and other published literature as well as visits to the relevant Army and Air Force program management offices (PMOs) and to the winning prime contractors of the respective systems. Nevertheless, the case study summaries in this chapter and the extended case study reports in the appendices do not necessarily represent the views of the PMOs or the contractors.

A. AH-64 APACHE ATTACK HELICOPTER SYSTEM

1. Background

The AH-64 was designed primarily to kill tanks. It carries the laser-guided Hellfire antitank missile as well as a 30mm Chain Gun and 2.75-inch rockets for suppressive fire. To complement the Hellfire, the AH-64 includes a sophisticated target acquisition/designation sight (TADS) including a laser range finder and tracker as well as a television camera and a forward-looking infrared (FLIR) system for night vision. Because the twin-engine AH-64 must operate in the forward battle area, it has been designed for survivability, including armor to withstand 23mm hits, one-engine-out capabilities, and crashworthiness. In addition, the AH-64 design effort has emphasized hovering capability and agility in flight since AH-64 tactics call for concealment behind terrain features prior to popping up to fire antitank missiles and then dropping back down for low-level nap-of-the-earth flight to another position. To complement the new tactics, the AH-64 includes a capable pilot night vision sensor (PNVS) including a FLIR as well as direct-view optics.

The Advanced Attack Helicopter (AAH) Program, which developed the AH-64, was initiated in November 1972 following cancellation of the Cheyenne Helicopter Program. The Cheyenne had been developed for the attack helicopter role and was ready for production.[1] It was cancelled in 1972 because its unit procurement cost (UPC) was considered to be too high and because it had been optimized for forward air speed and was not especially suitable for the newly developed AAH tactics.

In early 1973, five companies submitted paper proposals for the new AAH Program and in June 1973 Hughes Helicopters and Bell Helicopters were awarded cost-plus-incentive-fee (CPIF) contracts for a 36-month engineering development (ED) phase. The contracts called for design, fabrication and testing of two flying prototypes and one ground test vehicle by each contractor. The competitive phase was to end with a four-month development/operational test (DT/OT) of the new prototypes conducted by the Army to assist in the evaluation of contractor proposals for the follow-on, sole-source phase.

In priority, the AAH was among the top five Army development programs, but its recurring unit flyaway cost (i.e., excluding such costs as initial spares and support equipment) was required to be within a range from $1.4 to $1.6 million (in constant 1972 dollars) as compared to $2.7 million estimated for the Cheyenne.[2] The AAH was also to be 2000 pounds lighter than the Cheyenne, would exclude some of the Cheyenne's costly fire control and navigation equipment, and unlike the Cheyenne would not challenge the state of

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[1] Technical problems had forced cancellation of initial Cheyenne production in 1969.

[2] Recurring flyaway cost does not include certain nonrecurring costs included in flyaway cost.

aerodynamic art. The contractors were required to propose design-to-cost (DTC) goals for recurring unit flyaway costs and an incentive fee was made available for good contractor performance in achieving those goals. Many performance and other requirements were specified as bands, bounded by desirable and minimum acceptable values. To enable the contractors to achieve their DTC goals, they were given the flexibility to trade off (i.e., reduce) performance characteristics within the bands without prior PMO approval. Trade-offs below the minimum requirements were also possible but would require prior approval.

The competitive Phase 1 was considered an engineering development (ED) for the air vehicle but did not include integration of the mission subsystems (e.g., armament, fire control, visionics, navigation, communications). While provisions for subsystem integration were made in the DTC goals and while the space, weight and power requirements of the subsystems were considered in the air vehicle design, actual integration was delayed in order to reduce the cost of the competitive phase and take advantage of potential advances in the state of the art for certain subsystems. Contract costs for the competitive phase eventually amounted to $75.4 million for Bell and $99.2 million for Hughes. After a late start, the DT/OT was completed by September 30, 1976, best and final offers (BAFOs) for the contractor proposals for the follow-on, sole-source, full-scale engineering development (FSED) phase were submitted by November 22, 1976, and Hughes was selected by December 6, 1976.

2. Competitive Incentives to Control Cost

a. Value of Winning

The AAH competition was worth winning because the contractor selected for Phase 2 would eventually be in a sole-source position for a procurement program currently estimated to exceed $6 billion. In addition, foreign military sales (FMS) and commercial helicopter spin-offs were possible and the AAH would strengthen the winner's position in the helicopter industry. The AAH Program represented a make or break proposition for Hughes and winning increased Hughes' employment almost four-fold.

b. Credibility of Contractors

Bell was a solid company that still manufactured the AH-1 Attack Helicopter, which itself was derived from the UH-1 developed by Bell in the 1950s. Bell had in-house experience and facilities for medium-size helicopters (such as the AAH) and probably would have been the contractor if Phase 1 had been sole-source. Hughes had designed and produced the OH-6A Light Observation Helicopter (with 1/8th the empty weight of the AAH) in the 1960s. Hughes was a small company doing relatively little manufacturing in 1972 and had little in-house experience or facilities for a medium-size helicopter. Thus, Hughes knew it was an underdog and Bell had reason to be overconfident.

c. Importance of Cost among Program Objectives

It was clear from the start that unit procurement cost (UPC) would have an important impact on the selection of the Phase 2 contractor. This had been demonstrated in the selection of contractors for Phase 1 and was spelled out in the published criteria to be used in the evaluation of contractor proposals for Phase 2. Cost and performance were considered the most important areas and were to receive equal emphasis. Further, proposals with recurring unit flyaway costs exceeding $1.6 million (in constant 1972 dollars) would be considered nonresponsive.

d. **Validation of Cost Estimates**

As part of the DTC effort, regular reviews were conducted by the PMO at Hughes and its subcontractors to test the credibility of contractor cost estimates down to the detailed parts level. The estimates assumed particular production methods and equipment types, although the prototypes themselves were fabricated using development methods. The DTC estimates were weakened by the fact that the prototypes did not integrate the mission subsystems and due to the inclusion of numerous changes to the prototype designs (based, in part, on what was learned at the DT/OT) in the Phase 2 proposals.

e. **Priced Production Options**

The Phase 2 proposals did not include production options. Continued DTC effort, however, was to be motivated by an incentive fee of up to three percent of target cost.

f. **Competition during Follow-on Procurement**

There was no serious threat during Phase 1 that competition to produce the AH-64 design would be introduced during the procurement phase and a complete technical data package (TDP) was not required. The possibility of modifying the AH-1 or the UH-60A for the AH-64 role was considered during Phase 2 and rejected.

g. Correction of Design Deficiencies

Since the Phase 2 proposals did not include production options, no provision was made for contractor responsibility for the correction of design deficiencies.

h. Summary of Competitive Incentives

The competition clearly placed great importance on the control of unit procurement cost (UPC) and the contractors had to fear the Government's ability to validate their DTC estimates during the reviews, particularly due to the construction of prototypes. Nevertheless, the unit cost estimates still left ample room for error and the lack of priced production options or of a possibility of production competition left the Phase 2 contractor with little incentive to make the estimates come true.

3. Results of the Competition

a. Potential Unit Cost Savings

Hughes was awarded the Phase 2 contract on December 10, 1976, based on overall superior performance, survivability, payload, endurance, and reliability and maintainability. Hughes' proposed recurring unit flyaway cost was $1.556 million (in constant 1972 dollars), still below the $1.6 million ceiling but substantially above its original goal of somewhat more than $1.4 million. Hughes' DTC effort led to potential unit cost savings through cost/performance trade-offs and design efforts. The greatest single savings was due to Hughes' lightweight approach. Hughes originally proposed a primary mission gross weight of 13,200 pounds. The Phase 2 contract called for 13,825 pounds and the current production estimate is 14,694 pounds. That is still 1300 pounds less than the Army's maximum of 16,000 pounds, which Bell's DT/OT prototypes had already breached. Hughes pursued its lightweight design from the start, and demonstrated in static testing that its fuselage still provided the required strength. Other efforts to control weight included development of its own 30mm Chain Gun and redesign of the TOW (i.e., the originally specified antitank missile) launchers. Weight reduction efforts, however, did not include the use of exotic materials or technologies, which would have tended to increase unit cost. The lightweight approach was adopted in order to gain performance as well as cost advantages. A rough estimate is that the approach saved some $100 to $165 thousand per unit (in constant 1972 dollars), although this particular savings was offset by increased costs for other features (e.g., the highly survivable but expensive main rotor blades). The PMO's estimate of airframe costs increased only two percent during Phase 1. Thus, there is evidence that Hughes did take steps to control UPC during Phase 1.

b. <u>Cost Growth During Phase 2</u>

It is possible that Hughes' proposed $1.556 million recurring unit flyaway cost could have been achieved with proper motivation. The current estimate, however, is $2.810 million (in constant 1972 dollars), an increase of some 81 percent. Overall UPC (in constant 1972 dollars) increased from $2.36 million to $3.76 million during Phase 2, an increase of 59.3 percent. Since UPC for the average noncompetitive system discussed in Chapter III would have increased 34.8 percent over the same length of time, it is not apparent that the AAH competition led to lower UPC.

Much of the Phase 2 growth in UPC occurred for items that were not actually included in the Phase 1 prototypes. For the airframe itself (minus the engine), which was the principal subject of the prototype competition, unit hardware costs increased only 28 percent (in constant dollars). But unit hardware costs for the airframe included the costs of integrating the mission subsystems, which was not accomplished in the Phase 1 prototypes. While it is not possible to isolate the growth in integration costs, it is known that cost growth for the electrical area was particularly severe, with the number of wires required to interconnect the various subsystems quadrupling during Phase 2.

The growth in Phase 2 airframe unit cost was not due to immaturity of the design proposed for Phase 2. The only major change was the adoption of a movable, programmable horizontal tail surface that may have cost $17 thousand (in constant 1972 dollars) compared to the airframe unit hardware cost of $825 thousand (at the beginning of Phase 2). The weight gain during Phase 2 only amounted to six percent. Changes in Army requirements at the end of Phase 1 (including substitution of the Hellfire for the TOW missile, upgrading of the TADS and PNVS, and development of a new 30mm round) had a major impact on R&D costs, program schedule, and hence procurement costs in escalated (i.e., inflated) dollars. These requirements changes had relatively little impact on the airframe structure, but they did further complicate the subsystem integration task and affect requirements for such features as environmental control and electrical power generation. Further, the TADS/PNVS was developed in a separate competitive program during Phase 2, with a winning design not selected until April 9, 1980, and continuing design maturation efforts thereafter. This also may have made the task of planning subsystem integration more difficult.

Thus, it seems plausible that cost growth for the airframe itself (minus the integration task), which was the principal subject of the Phase 1 competition, was relatively low and perhaps even some savings were achieved as a result of the competitive DTC effort. But it is not possible to isolate any such savings.

4. Conclusion

While the AH-64 Program has experienced unusually large growth in unit procurement cost (UPC), this does not reflect on the effectiveness of prototype competition. The prototype phase was limited in scope, testing only the airframe and excluding subsystem integration and support. Further, the competitive incentives terminated at the end of Phase 1. There were no competitively priced production options to motivate Hughes to make its DTC proposal come true even for the airframe. And most other system costs (except for the TADS/PNVS) were determined in a sole-source environment.

B. M-1 ABRAMS TANK SYSTEM

1. Background

In order to perform its offensive role in the forward battle area, the M-1 Tank was designed for survivability (e.g., new special armor), lethality (e.g., accurate, automatic fire control), and mobility (e.g., 1500-horsepower engine, stabilization and suspension for fire-on-the-move capability). Like the AH-64, the M-1 was preceded by a development program (for the MBT-70/XM-803 Tank) that was cancelled due to excessively high unit costs and because it did not adequately satisfy the Army's needs. The Army studied its tank requirements and initiated the XM-1 Program in 1972, and awarded competitive advanced development (AD) contracts for the XM-1 to Chrysler and General Motors (GM) in June 1973.

The program was accorded very high priority within the Army and, due to Congressional pressure, was placed on a short seven-year schedule (from inception to initial operational capability (IOC)) requiring considerable concurrency. Under the 34-month AD phase, each contractor was to design, fabricate and test a completely integrated prototype system (including all subsystems except for night vision) plus an automotive test rig and a ballistic hull and turret. The AD phase would end with an Army development/operational test (DT/OT) to validate the contractors' proposals for full-scale engineering development (FSED) in a sole-source Phase 2. The CPIF contracts eventually amounted to $68.999 million for Chrysler and $87.969 million for GM.

A design-to-unit hardware cost (DTUHC) goal was established at $507,790 (in constant 1972 dollars) compared to unit cost estimates of $339 thousand for the existing M60A1 Tank and $611 thousand for the cancelled XM-803. The XM-1 design was to achieve substantial improvement over the M-60 but performance requirements were prioritized and many were specified as bands to prevent over-sophistication on the one hand and assure adequate performance on the other. The contractors were allowed to make cost/performance trade-offs within the bands and, upon prior PMO approval, outside the bands as necessary to achieve the DTUHC goal. The source selection for Phase 2 was made on schedule in July 1976 but OSD required that the Army solicit new proposals and make another source selection in November 1976. The delay resulted from an agreement with the Federal Republic of Germany (FRG) that potentially would lead to substitution of a 120mm for the 105mm main tank gun and the use of a gas turbine engine. OSD delayed the source selection so that the Army could solicit competitive proposals that reflected these potential changes.

2. Competitive Incentives to Control Cost

a. Value of Winning

The winner of the Phase 2 award would be in a sole-source position as prime contractor for potential R&D and procurement contracts then estimated at more than $5 billion, with strong prospects for additional foreign military sales (FMS). Within the contractor divisions that were responsible for the respective efforts, such amounts would be noticeable; indications were that the contractors were both highly motivated.

b. Credibility of Contractors

Both GM and Chrysler were well-qualified contenders. GM had been the development contractor for the cancelled XM-803 Tank and thus was schooled in the latest tank technology. Chrysler was currently producing the M-60 Tank and was given access to the XM-803 technology by the Army. As Phase 1 progressed, all indications were that both companies would be successful in developing their prototypes.

c. Importance of Cost among Program Objectives

The criteria governing the selection of a Phase 2 contractor indicated that cost and the combination of engineering design/operational suitability would be of "paramount and interrelated" importance. Within the cost area, unit hardware cost was considered most important. Thus unit cost would be a key to winning the competition. The Army, however, left open the question of whether, once the

DTUHC was achieved, additional efforts should seek to improve performance or reduce cost yet further. The contractors adopted opposite strategies in this regard.

d. Validation of Cost Estimates

The Army made a serious effort to validate unit cost estimates, both as part of the source selection process and through detailed DTUHC reviews with the contractors during Phase 1, making use of prototype data, vendor quotes, and analysis at the parts level. The fact that the prototypes integrated all subsystems (except the night vision) made the prototype experience particularly useful.

e. Priced Production Options

The Army originally planned only an award fee to motivate DTUHC achievement in Phase 2. But at the last minute the Army introduced a requirement that the Phase 2 proposals include production options with firm ceiling prices for recurring hardware cost and covering an FY79 buy of 110 units and an FY80 buy of 352 units, or 6.5 percent of the total buy. The ceiling prices were narrow in scope, excluding costs for such items as facilitization, peculiar support equipment and initial spares, since the options would not be exercised for two and one-half years and a broader scope would have increased contractor risk too much. While the ceiling price requirement influenced the Phase 2 proposals and subsequent development and production efforts, it was imposed too late to influence the prototypes themselves.

f. Competition during Follow-on Procurement

The possibility of reintroducing competition during the production phase was held open by the requirement for a complete technical data package (TDP) and by announcement before the source selection for Phase 2 that the Army would establish two tank assembly facilities for the M-1. Nevertheless, the plants each specialized in different component manufacturing and it would have been expensive to equip them to stand alone. Thus, the threat of production competition would have been meaningful only if the winning contractor developed extremely serious cost or other problems.

g. Correction of Design Deficiencies

The Phase 2 production option proposals were required to include contractor responsibility for the (development and hardware) costs of correcting design (and other) deficiencies that prevented production tanks from meeting contractual specifications for performance and other requirements. The contractors were required to propose a line item target cost for this provision and it was included within the overall price ceilings.

h. Summary of Competitive Incentives

The structure of the M-1 Program provided a better chance for the control of unit procurement cost (UPC) than did the structure of the AH-64 Program. The M-1's well-matched competitors were required to develop integrated prototype systems so there would be fewer questions left open (at least for the tank itself) for the follow-on phase. The contractors were required to commit to firm price ceilings to back up their DTUHC estimates. A potential weakness, however, was that the two and one-half year delay until production caused the ceiling prices to be narrow in scope, permitting (or potentially inducing) cost growth in areas not covered.

3. Results of the Competition

a. Design-to-Cost (DTC)

Chrysler was awarded the CPIF Phase 2 FSED contract on November 12, 1976. The FSED was to last 36 months, overlapping the initiation of low-rate initial production (LRIP) by six months. Chrysler's proposal indicated that it would be able to better the $507,790 DTUHC goal by $11,000 per unit (in constant 1972 dollars). Significant savings (in recurring unit hardware cost) were achieved in the fire control, suspension and other areas in order to offset the higher acquisition cost of the turbine engine. For example, some $30,000 per unit was saved by using a hybrid stabilization system for the gunner's primary sight. Other fire control savings were obtained for the computer, the laser range finder, and the main gun auxiliary telescope. Using a torsion bar rather than a hydropneumatic suspension system saved some $22,000 per unit. Many of the savings were achieved with little or no degradation of performance. In other cases, such as elimination of the commander's independent sight, capabilities were degraded. Also, some components chosen to lower acquisition cost, such as the truck quality starter, may prove inadequate and be replaced.

These savings were necessary to permit Chrysler to use a gas turbine engine. The turbine had higher acquisition cost but potentially lower life cycle cost (LCC).[1] It also had certain performance advantages. Further, it was substantially lighter and smaller than the comparable diesel and thus permitted Chrysler to improve its armor protection without exceeding the maximum weight requirement.

b. Phase 2 Cost Growth

The estimate of unit procurement cost (UPC) for the M-1 Tank increased 33.9 percent from $595,000 to $797,000 (in constant 1972 dollars) from November 1976 to December 1982. If the incremental cost of the new model (with the 120mm gun and a number of other capability improvements) to be introduced in 1985 is excluded, the UPC estimate increased only to $747,000. This is 25.6 percent above the November 1976 estimate and somewhat below the 34.8 percent that UPC for the median noncompetitive system discussed in Chapter III would have grown over a comparable period. The DTUHC estimate, which was the principal focus of the prototype competition, is currently estimated at $567,700 (in constant 1972 dollars), an increase above the goal of 11.8 percent since it was established ten years ago.[2] Thus, there is substantial evidence that the prototype competition led to lower recurring unit hardware costs than would otherwise have occurred.

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[1]Even after design problems with the turbine had been corrected, manufacturing problems, including poor quality control and late deliveries, were experienced.

[2]GDLS estimates that, excluding cost growth due to Army-directed program changes, the DTUHC estimate would be $533,400, an increase of only 5.0 percent in ten years.

Implementation of the production ceiling prices proved difficult and negotiations over escalation of the ceilings for inflation and engineering changes proved contentious. The Government had difficulty collecting all of its claims under the correction of deficiencies provision and the ceiling price benefit was partially eroded by subsequent negotiations for an initial spares contract. It is not clear whether the lack of a ceiling on Government-funded facilitization costs led to any uneconomical increases in production equipment (in order to reduce recurring hardware costs, which were under a ceiling). It is clear, however, that the ceilings motivated Chrysler to continue its cost control effort during the sole-source Phase 2.

4. Conclusion

The prototype competition for the M-1 Tank did achieve savings in unit procurement cost (UPC) compared to what UPC would otherwise have been. Thus, the M-1 Program exemplifies the value of integrating the complete system during the prototype phase as well as the ability of competitively negotiated ceiling prices to motivate continued cost control during the follow-on phase. The narrow scope of the ceiling prices and their limitation to only 6.5 percent of the total planned buy, however, did permit substantial cost growth to occur. But since production would not be initiated until two and one-half years following the competitive phase, contractor risk limited the Government's ability to broaden the scope of the ceiling prices.

C. M-247 SGT. YORK AIR DEFENSE GUN SYSTEM

1. Background

The Sgt. York (also known as DIVAD) was designed to provide short-range air defense for mechanized units in the forward battle area. The system includes twin 40mm guns mounted in an M48A5 Tank chassis. Fire control is fully automatic, with a digital computer to control gun-pointing based on input from surveillance and tracking radars. As a backup to the radar system, the Sgt. York includes a laser range finder and optical sights, including a low-light night vision sight.

Use of a digital computer for second-order fire control solutions for the air defense role was demonstrated in the Gun Low-Altitude Air Defense (GLAAD) Test Program between 1973 and 1976. The Army initiated the DIVAD Program in August 1976 and competitive engineering development contracts were awarded on January 13, 1978 to Ford Aerospace and Communications Corporation (FACC) and General Dynamics-Pomona (GDP).

Due, in part, to Congressional pressure, the DIVAD was given a short development schedule requiring considerable concurrency. The contractors were encouraged to utilize mature components and no formal advanced development (AD) phase was conducted. Instead, the program began with full-scale engineering development (FSED). The contractors were each required to design, fabricate and test two fully integrated prototype gun systems, culminating in an Army three-month development/operational test (DT/OT) to validate contractor proposals for a sole-source Phase 2. The competitive, 29-month FSED phase was conducted on a "hands off" basis under fixed-price (FP), best-efforts contracts. Thus, the contractors were given unusual freedom from reporting requirements and Government interference in their design efforts. A design-to-cost (DTC) goal of $1.9 million (in constant 1978 dollars) was established for unit rollaway costs. The contractors were given the flexibility to make cost/performance trade-offs to achieve the DTC goal, based on 43 prioritized characteristics and 12 firm performance specifications. Army requirements were held unusually stable during the DIVAD development effort. As it turned out, problems with the prototypes were responsible for a delay in the DT/OT and it was extended to five months in duration. Phase 1 contract costs amounted to $43.4 million for FACC and $42.8 million for GDP.

2. Competitive Incentives to Control Cost

a. Value of Winning

The Sgt. York Program is now estimated to cost over $4 billion. The Phase 2 contract would include additional development plus production options for 276 of the planned 618 systems and would put the winner in an excellent position to receive the follow-on production award. There is also a potential for foreign military sales. The value of the potential contract induced both competitors to expend significant company funds in addition to those provided by the FP contracts.

b. Credibility of Competitors

Both contractors were solid contenders. FACC had been the development contractor for the GLAAD effort mentioned above and had ordnance and other relevant experience. GDP had developed the radar-directed Phalanx Air Defense Gun System for the Navy. In addition, the mature-components strategy significantly reduced the risk of successfully developing prototype systems in time for the DT/OT.

c. Importance of Cost among Program Objectives

For the Phase 2 source selection, system performance and cost were considered to be the most important criteria and carried equal weight. Investment cost (including procurement) was given priority within the cost area, and special attention was paid to correlation of unit cost estimates with the DTC goal. In addition, continuing budget problems made the competitors aware that control of procurement costs was important to avoiding cancellation or cuts in the DIVAD Program.

d. Validation of Cost Estimates

Unusually great reliance on mature components improved cost estimates by reducing the uncertainty attached to starting up the production of new items. Further, the Phase 1 prototypes were completely integrated, including all mission subsystems. On the other hand, Phase 1 did not include detailed DTC reviews and the "hands off" approach may have limited the PMO's ability to validate costs. Nevertheless, a bottoms-up estimate was made for the source selection.

e. Priced Production Options

The Phase 2 proposals were required to include production options with firm ceiling prices for the FY82-84 buys encompassing 276 fire units or 45 percent of the total planned buy. The options were comprehensive and the ceilings covered production costs for the fire units as well as ammunition, initial spares and repair parts, and training and peculiar support hardware. A cost ceiling was also established for

Government-provided special production tooling and test equipment and for the Phase 2 R&D effort. Production was expected to begin one year after the source selection for Phase 2.

f. Competition during Follow-on Procurement

The Phase 2 proposals were required to provide for complete technical data packages (TDPs) to be delivered in time to permit competition for the follow-on Phase 3 buy of 342 fire units. The Army was serious about the possibility of competing the Phase 3 award and may still do it. This may have given the Phase 1 competitors additional motivation to control unit costs, although a new bidder for Phase 3 would be at a serious disadvantage due to start-up costs, since 45 percent of the buy will already have been awarded.

g. Correction of Design Deficiencies

The Phase 2 production options were required to include contractor responsibility for correcting deficiencies due to design (or other) flaws that would prevent production systems from meeting contractually specified requirements for performance and reliability and maintainability. Necessary design and hardware corrections would be made within the firm ceiling prices of the production options, although this provision was not priced as a separate line item.

h. Summary of Competitive Incentives

The competitive structure of the Sgt. York Program provided even stronger incentives for the control of unit procurement costs (UPC) than did the structure of the M-1 Program. The comprehensive, priced production options placed a ceiling on most elements of UPC for 45 percent of the total buy. Further, the competitors were well-matched, the Phase 1 prototypes were completely integrated systems, correction of design deficiencies was required, and there was a credible threat that the Army would compete the Phase 3 production award.

3. Results of the Competition

a. Design Savings

The Army's design-to-cost (DTC) goal (including the contractor goal for recurring unit hardware cost as well as nonrecurring costs, Government-furnished equipment (GFE), and related items) was established at $1.90 million per fire unit (in constant 1978 dollars), while the current estimate of these costs is $1.82 million (in constant 1978 dollars). Compared to the estimate at the beginning of Phase 1, savings were achieved particularly in the fire control and turret/drive subsystems. Further, a major savings was achieved in ammunition costs which are not included in the DTC goal.

The ammunition savings resulted from FACC's use of the 40mm gun with a proximity-fused (PX) round. The PX round detonates in the vicinity of its target (rather than on impact) and is particularly useful for improving accuracy at long distances. The PX round both improved performance and permitted a substantial reduction in the number of rounds required to defeat a given number of targets, and thus reduced total procurement costs. Without competition, the Army would probably have specified a 35mm gun without the PX round.

Savings were also achieved through cost/performance trade-offs. Some $10-20 thousand per unit was saved because FACC did not believe "closed loop" fire control was necessary, especially in light of the accuracy resulting from use of the PX round. Nearly $400 thousand per unit were saved by trade-offs that degraded performance (but not below minimum requirements) in the areas of night vision, nuclear survivability, and power source redundancy.

b. Cost Growth

Currently, unit procurement cost (UPC) is estimated at $3.263 million (in constant 1978 dollars), 1.3 percent below the November 1977 estimate prior to the competition. Over a comparable period, UPC for the median noncompetitive program discussed in Chapter III would have increased 29 percent. This outstanding achievement was greatly aided by the considerable use made of mature components. But competition had an important impact in motivating the contractors to select mature components. What is more, the current UPC estimate is particularly reliable owing to the existence of firm ceiling prices covering nearly 45 percent of total procurement costs.

4. Conclusion

The control of UPC evidenced by the Sgt. York Program provides strong testimony to the potential impact of a well-structured R&D competition. The comprehensive scope of the ceiling prices, the substantial portion of the total buy that was covered by the production options, the high degree of design flexibility accorded the contractors, the heavy reliance placed on mature components, and the stability of Army requirements all contributed to a substantial savings in UPC compared to what it would have been without competition.

D. AGM-86B AIR-LAUNCHED CRUISE MISSILE

1. Background

The Air-Launched Cruise Missile (ALCM) is an air-to-ground missile designed for launch (both internally from the bomb bay and externally from wing pylons) from B-52 and B-1 bombers. The ALCM's mission is strategic and it can carry its nuclear warhead over 1500 miles with remarkable accuracy. Its range would permit it to be launched from stand-off (i.e., outside Soviet air space) as well as penetrating aircraft. The ALCM is powered by a miniature turbofan engine and is guided by a radar-dependent, terrain-following TERCOM guidance system.

The ALCM Program grew out of the Air Force's cancelled Subsonic Cruise Armed Decoy (SCAD) Program, and was approved by OSD for advanced development (AD) in February 1974. At the same time, the Navy initiated its Sea-Launched Cruise Missile (SLCM) Program. The ALCM and the SLCM were to use essentially common engines and navigation systems, but the airframes had to be different sizes since the ALCM was to be launched from a B-52 bomb bay and the SLCM from a submarine torpedo tube. While the SLCM AD was a competitive prototype program, the ALCM AD was conducted by the Boeing Aerospace Company on a sole-source basis. While modification of the SLCM to perform the ALCM role was considered repeatedly, the AD programs remained separate and the respective systems were designed to meet different specifications.

The ALCM and SLCM Programs were approved for full-scale engineering development (FSED) in January 1977 and a Joint Cruise Missiles Project Office (JCMPO) was established to manage them. Following the July 1977 cancellation of the B-1 Bomber Program, DoD directed that a competitive FSED program be established to develop an ALCM with greater range than that previously considered in the Boeing program. Greater range was necessary since, without the B-1, more emphasis would be placed on the capability of launching the ALCM from stand-off ranges outside Soviet air space.

The ALCM Program was to be accelerated from its previous schedule and concurrency was increased. Competition was introduced in order to control schedule and cost risks in a program of great national urgency, although the technical risks themselves were not considered great. Boeing and General Dynamics (which had won the SLCM AD competition) were awarded contracts in February 1978 to design and fabricate preproduction prototype missiles for ten test flights. The test program, to be conducted between July 1979 and February 1980, required integrated launches from both the B-52 bomb bay and from its wing pylons. The competitive program was to include pilot production by each contractor of 12 missiles in FY78 and 12 more in FY79. Overall, the competition was expected to cost $409.3 million for Boeing and $297 million for General Dynamics.

The principal subjects of the competition were the airframe, missile integration with the B-52, guidance software, and support. The engines and the guidance hardware were essentially common for the two designs. Bands were established between operational requirements and goals for certain factors in order to permit contractor design trade-off flexibility.

2. Competitive Incentives to Control Cost

a. Value of Winning

The ALCM Program is substantial, with procurement costs estimated at the beginning of the competitive phase to be $3.3 billion.[1] In a sense, Boeing may have been hungrier than General Dynamics since Boeing Aerospace had not won a major military contract for some time and was shrinking relative to Boeing's commercial divisions. General Dynamics was in a more comfortable position since its role as SLCM developer was not being challenged. Nevertheless, the ALCM profit potential appealed to both companies and they were both highly motivated.

b. Credibility of Contractors

The competitors were well-matched. Boeing had already tested six prototype missiles during its AD phase, including integrated B-52 launches, and had planned for commonality with existing support equipment. General Dynamics had already won the SLCM prototype competition and had some experience air-launching its missile from A-6s. General Dynamic's sole-source position for potential production contracts for 1200 SLCMs also promised to give it a cost advantage through the sharing of fixed costs between the two programs.

c. Importance of Cost among Program Objectives

For the production source selection, operational design/utility was considered the most important criterion, and included life cycle cost (LCC) as one of six equally

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[1]This amount, however, was not guaranteed, as the recent cancellation of ALCM production after FY84 demonstrated.

important factors. LCC, in turn, included unit flyaway cost as one of six unranked factors. Thus, unit procurement cost could be expected to be very important to the source selection.

d. Validation of Cost Estimates

The Air Force was in an excellent position to validate unit cost estimates, since the FSED prototypes were considered preproduction prototypes and could be expected to require only minor design changes following the competitive testing. As mentioned above, the competition included pilot production of 24 missiles by each competitor to demonstrate production capabilities and provide additional information on production methods and costs. Detailed cost estimates were built up based on part-by-part analyses to support the production proposals.

e. Priced Production Options

At the end of the FSED competition, the contractors were required to submit production proposals with firmly priced ceilings for the FY80 buy of 225 missiles and the FY81 buy of 480 missiles. This amounted to 21 percent of the 3418 missiles planned at the time. Ceilings were established for the missiles themselves as well as for operational support hardware and Government-furnished special tooling and test equipment (ST/STE). Ceilings were not established for initial spares and repair parts or for depot support hardware. The FY80 production contract was awarded immediately after the source selection.

f. Competition during Follow-on Procurement

The competitive production proposals were required to include priced options for a potential leader/follower arrangement to reintroduce competition during the production phase. Under the option, the ALCM production contractor would hold a competition to select a follower contractor and would assist that follower in initiating ALCM production, motivated in part by an award fee. The leader and follower would thereafter compete for shares of ALCM production. The contractors had every reason to expect that the leader/follower option would be exercised.[1]

g. Correction of Design Deficiencies

The production proposals were required to include provisions for an availability guarantee whereby the contractor would be responsible (under a firm ceiling) for design (and other) corrections to assure that a specified level of missile availability was achieved, as determined by ground testing. In addition, an award fee was made available for superior missile availability in operational test flights.

h. Summary of Competitive Incentives

Like the Sgt. York Program, the ALCM Program was particularly well-structured to provide competitive incentives for the control of unit procurement cost (UPC). The prototype systems were completely integrated, and the competitively determined ceiling prices were comprehensive. The ALCM competition was especially distinguished by the emphasis

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[1]It has not been exercised, but similar production competition has been introduced in the SLCM Program.

placed on production planning, including pilot production during the competitive phase. Unlike even the Sgt. York Program, the production contract was awarded immediately following the source selection.

3. Results of the Competition

a. Design and Production Savings

Boeing was selected for the production contract in March 1980 and the contract was awarded in May 1980. When the FSED competition was first announced, Boeing established a producibility task force to identify design changes to reduce production costs in anticipation of submitting its priced production proposal. The changes identified were estimated to have reduced missile unit costs by 30 percent compared with previously planned methods and included substitutions of materials and using castings or die forgings to reduce machining costs. While producibility design changes would have occurred even without competition, it is noteworthy that the competition was initiated after the design was relatively mature from a performance point of view and that these producibility changes were demonstrated in the FSED prototypes and pilot production missiles prior to the source selection.

The most significant change was the adoption of net-shape casting for the missile body. Boeing's design had a trapezoidal cross section in order to make efficient use of space on the rotary launcher (for internal launch from the B-52). This shape led Boeing to plan to weld together 28 intricately machined forged aluminum rings in fabricating its missile body. This method, however, proved to be very expensive, due both to machining requirements and to the difficulty of achieving adequate welding quality. After the competition was announced, Boeing decided instead to form the missile body (i.e., the fuel tank) by bolting together four large, complex aluminum castings requiring machining primarily at the mating surfaces, thus reducing machining requirements by 80 percent. The technology involved was relatively new, its use was considered risky, and it forced Boeing to rely on outside suppliers for its airframe. Cost and schedule risks might eventually have driven Boeing to adopt net-shape casting even without competition, but Boeing had good reasons to resist it. Further, it is not clear that the Air Force would have accepted the technique if the prototype competition had not allowed Boeing to demonstrate it prior to the source selection. It was estimated that net-shape casting would reduce production costs by $100 million (in FY1977 dollars) for 3,394 missiles.

After Boeing had won the FY80 production contract, it continued to make design and production method changes to enable it to make a profit at the competitively determined ceiling prices. A straight cast nose and a complex titanium casting for the elevon mechanism housing were both adopted following the source selection. Once production began, Boeing achieved an outstanding reduction in basic factory labor (BFL) hours, which dropped from 5669 for the first FY80 unit to 1310 for the final, 225th unit. The assumed improvement curve would have predicted 1500 hours for the 705th unit at the end of the FY81 buy. BFL hours have continued to drop during FY81 production and have now reached 1000 hours. Cost control was greatly aided because Boeing invested in a new plant for the ALCM, including a dedicated, state-of-the-art machine center (which would not have been provided without competition), and because Boeing maintained competitive sources for the large fuel tank castings.

b. Cost Growth

The estimate of unit procurement cost (UPC) for the ALCM increased from $675 thousand in January 1977 to $1.021 million in December 1982 (in constant 1977 dollars). This increase includes an unexpected reduction in the planned buy from 3418 to 1523 units.[1] Thus, the cost growth is largely due to the spreading of fixed costs over a much smaller quantity than was intended. UPC in September 1982 (prior to the reduction in quantity) was estimated at $769 thousand (in constant 1977 dollars) for an increase of only 13.9 percent over the January 1977 estimate. Since the UPC for the median noncompetitive program discussed in Chapter III would have increased 34.8 percent over a comparable period, it is apparent that UPC control in the ALCM Program has been effective. It is also apparent that a substantial portion of the potential savings generated by the competition will not be realized due to the elimination of future ALCM production.

4. Conclusion

The ALCM competition, like the Sgt. York competition, exemplifies the substantial savings in unit procurement cost (UPC) that can be achieved by a well-structured program. Particularly noteworthy is the fact that these savings were achieved after the ALCM design was relatively mature from a performance point of view and did not degrade missile performance. The ALCM Program also illustrates that R&D prototype competition can be a risky investment. Analogous to

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[1] Planned ALCM procurement was 3418 in January 1977 and 1523 in December 1982. Subsequently, an additional buy of 240 units (in FY84) was planned. The truncation of the ALCM Program is reportedly due to a decision to develop an advanced ALCM using "stealth" technology. See National Journal, March 26, 1983, page 644.

Boeing's investment in plant and equipment for the ALCM, the Government made a substantial investment in R&D competition in the expectation of future benefits through reduced UPC. Truncation of the program will prevent those benefits from being fully realized.

CHAPTER V

ANALYSIS OF R&D PROTOTYPE COMPETITION

This chapter uses the information discussed in previous chapters to address the four principal questions of the study, namely:

- Does prototype competition during the R&D phase result in lower production costs?
- Do these downstream savings compensate adequately for the incremental, up-front costs of using competition?
- At what point within the R&D phase does it appear from these data that competition should be terminated?
- What economic criteria would assist in judging the desirability of R&D competition for particular systems.

A. IMPACT OF R&D PROTOTYPE COMPETITION ON UNIT PROCUREMENT COST

- Does prototype competition during the R&D phase result in lower production costs?

The data of this study indicate that, on average, R&D prototype competition does result in lower unit procurement cost (UPC). Further, the extent of such cost savings depends on the manner in which the competitive program is structured.

The Selected Acquisition Report (SAR) data analyzed in Chapter III showed that the median annual rate of growth in UPC was 3.1 percent for a sample of 14 programs that included R&D prototype competition and 5.8 percent for a sample of 27 programs without such competition. Inspection of the samples indicated that they were reasonably representative with respect to the weapon systems included and that other differences in sample characteristics did not appear adequate to explain the difference in UPC growth rates. These data, then, suggest that prototype competition has impacted UPC. Nevertheless, as discussed in Chapter III, this evidence by itself is not conclusive due to the small sample sizes and the considerable variation in UPC growth rates among the individual programs included.

That prototype competition can lead to lower UPC is further supported by the findings of the four case studies summarized in Chapter IV. As expected based on the discussion of competition in Chapter II, average annual UPC growth rates tend to depend on how well-structured a competitive program is as regards providing incentives to control UPC. That is evidenced in Table 4 which compares growth rates for the four programs listed in order of increasingly more effective structures for controlling UPC. That is:

- the AH-64 Program did not result in competitively priced production options and the competitive prototypes did not integrate mission subsystems;
- the M-1 Program did integrate subsystems and included competitively priced production options, but only for recurring unit hardware cost and only for 6.5 percent of the total buy;
- the M-247 competition included fully integrated prototypes and resulted in priced production options covering most procurement costs for 45 percent of the total buy;
- the AGM-86B competition included integrated prototypes, priced options covering 21 percent of the originally planned buy, and also included pilot production of 24 missiles by each competitor.

Thus, for this small sample, UPC growth rates tend to be lower for the programs with more effective competitive structures.

Table 4. COMPARISON OF CASE STUDIES

PROGRAM	AVERAGE ANNUAL PERCENTAGE CHANGE[1]	
	UNIT PROCUREMENT COST (UPC)[2] (PERCENT)	UNIT COST OF COMPETITIVE PORTION[3] (PERCENT)
AH-64 Attack Helicopter	9.9	4.7
M-1 Tank	4.3	2.0
M-247 Air Defense Gun	-0.3	-0.3
AGM-86B Air-Launched Cruise Missile	2.3	2.3

[1]Change is calculated from time of development estimate (DE) to December 1982, except that ALCM change is calculated to September 1982.

[2]UPC for M-1 Tank excludes incremental cost of future M1E1 model.

[3]Reports unit cost change for aspect of system that was principal focus of prototype competition. This was the airframe for the AH-64, recurring rollaway cost for the M-1, and UPC for the M-247 and AGM-86B.

As Table 4 indicates, cost growth was lower for the portion of UPC that was emphasized during the competition. For the AH-64, this was the airframe (as opposed to the engine or the mission subsystems). For the M-1, this was the tank itself (as opposed to support hardware, production facilitization, or initial spares). Both of these competitions were followed by extended, sole-source, full-scale engineering development (FSED) phases while the M-247 and AGM-86B competitions occurred during FSED.

In addition, the case studies revealed specific examples of contractor efforts motivated by competition to control unit procurement cost. These examples indicate that R&D competition can affect procurement costs at all stages of the development effort, from the determination of requirements through the implementation of production. There were major design innovations that reduced production costs without degrading performance:

- Hughes developed a lightweight airframe for the AH-64 that reduced costs and improved performance. Without prototype competition, Hughes would probably not have been the development contractor.
- Ford Aerospace selected and improved the 40mm proximity-fused (PX) round for the M-247, improving long-distance accuracy above specified goals and permitting a large reduction in ammunition requirements and costs. The Army had been leaning toward a 35mm gun and no PX round.

Intense design-to-cost (DTC) efforts led to design trade-offs that reduced unit costs without significantly degrading system functional capabilities:

- Chrysler adopted a hybrid fire control stabilization method and a torsion bar suspension system to reduce M-1 costs (compared to its competitor and to the previous tank development program for the XM-803) while still providing an outstanding fire-on-the-move capability.

- Ford eliminated the closed-loop method of fire control as being unnecessary and too costly, even though it was on the Army's list of desired features and Ford's competitor did propose it.

Design-to-cost (DTC) efforts also led to some degradation of performance (without going below minimum requirements) through the elimination of capabilities that were judged to cost more than they were worth in light of the Services' priorities and DTC goals:

- Chrysler downgraded the commander's station (relative to the features of the XM-803 and the West German Leopard 2 Tank), eliminating power traverse for the machine gun and an independent commander's sight.
- Ford downgraded night vision capabilities, nuclear survivability, and radar power source redundancy (relative to the features originally desired by the Army).

Even after system designs were relatively mature from a performance point of view, producibility changes to the designs and to production methods had important cost-reducing impacts:

- Boeing changed its AGM-86B airframe construction from 28 forged rings to four thin-walled aluminum castings for a dramatic reduction in production costs. The method of net-shape casting was considered new and risky and was adopted only after competition was introduced in the middle of the development program.
- Boeing invested in dedicated, state-of-the-art fabrication equipment (that it would not have acquired without competition) and achieved an exceptional reduction in unit labor hours during ALCM production, over and above normally expected "learning" improvements.

In addition to reducing production costs, competition had an impact on contract prices as such, and hence on contractor profits:

- Government costs for initial production contracts are expected to be at or near ceiling price levels for the three programs with competitively determined ceilings, suggesting that competition forced the contractors to bid low.
- The ALCM PMO found that Boeing's demonstrated ability to reduce costs during execution of its competitively determined FY80 production contract aided the Government in obtaining a reasonable price during sole-source negotiations for the FY82 production contract.

Competition also allowed the Government to obtain unusually favorable terms and conditions in the initial production contracts:

- Both Chrysler and Ford agreed to accept responsibility for correction of design deficiencies in production systems, and Boeing agreed to an availability guarantee, all within firm ceiling prices.
- Ford agreed to risk anticipatory financing of certain production costs in order to protect its production schedule, even though the Government was not yet obligated to reimburse Ford.
- Both Ford and Boeing agreed to firm ceiling prices for R&D contracts following their respective competitive phases, even though R&D contracts are typically cost-plus contracts.

In some cases, DTC decisions made during the competitions were subsequently reversed, and some cost/performance trade-offs remain controversial. But examples such as those cited above suggest that the lower UPC growth rates for programs with R&D prototype competition represent real savings.

B. COMPARISON OF THE COSTS AND SAVINGS FROM R&D PROTOTYPE COMPETITION

- Do the downstream savings from R&D prototype competition compensate adequately for the incremental, up-front costs of using competition?

Data from the four case studies indicate that UPC savings from R&D prototype competition can substantially outweigh its incremental costs. The balance between savings and costs, however, depends on the peculiar characteristics of each competitive program.

In this analysis, the incremental cost of competition is considered to be the cost of the second R&D contract, estimated as the average of the two contracts awarded.[1] The savings are estimated as the difference between estimated procurement costs as of the December 1982 SAR and what those costs would have been if UPC had increased at the same 5.8 percent rate as did UPC for the median noncompetitive program discussed in Chapter III.[2] As indicated in Column 4 of Table 5, estimated savings are greater than incremental costs for each of the three case studies where savings were realized. At the same time, it is clear that the ratio of savings to costs depends greatly on how large estimated procurement costs are relative to the competitive R&D costs. When procurement costs are relatively large, competitive R&D can exert tremendous leverage over procurement costs. Because the ALCM competition occurred during a standard FSED phase and included pilot production, it was more expensive (relative to procurement costs) than the other competitions and the margin

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[1]Competition may have other impacts on development costs. For example, some of the source selection and program management efforts of the developing Service must be increased to accommodate the additional contractor. On the other hand, competitively inspired contractor cooperation may reduce the need for Government oversight and may reduce the cost of the R&D contract itself (compared to what a sole-source developer would cost).

[2]As discussed in Chapter IV, the M-1 calculations exclude the incremental cost of the future M1E1 model, and the ALCM calculations are based on September 1982 estimates prior to the truncation of the ALCM Program.

Table 5. COMPARISON OF COSTS AND SAVINGS FROM COMPETITION

	MILLIONS OF CONSTANT BASE YEAR DOLLARS[1]					
PROGRAM	(1) INCREMENTAL COST OF R AND D COMPETITION[2]	(2) TOTAL PROCUREMENT COST[3]	(3) RATIO OF COLUMN 2 TO COLUMN 1	(4) ESTIMATED SAVINGS FROM COMPETITION[4]	(5) RATIO OF COLUMN COLUMN (4) TO COLUMN (1)	(6) DISCOUNTED RATIO OF COLUMN (4) TO COLUMN (1)[5]
AH-64	$ 76.9	$ 1,938.0	25.2	–	–	–
M-1	65.0	5,271.3	81.1	$384.8	5.9	2.4
M-247	38.8	2,016.4	52.0	619.0	16.0	9.9
AGM-86B	301.2	3,267.2	10.8	597.9	2.0	1.2

[1]Base years are FY 1972 for AH-64 and M-1, FY 1978 for M-247, and FY 1977 for AGM-86B.

[2]Average cost per contractor of competitive development contracts.

[3]As of December 1982 except as of September 1982 for AGM-86B. Does not include M1E1 costs for M-1.

[4]Assumes unit procurement cost (UPC) would have increased 5.8 percent for each year since FSED was approved without competition.

[5]Ratio of present value (in base year) of column (4) to present value of column (1) using a 10 percent discount rate.

between estimated savings and incremental costs is relatively small (although the estimated savings are still greater than the incremental costs).[1]

The data on Table 5 are stated in terms of constant dollars (for the base years of the respective programs) since inflation would otherwise tend to overstate the value of the estimated savings relative to that of the incremental costs.[2] But even apart from the impact of inflation, a dollar spent "up front" to implement competition is worth more to the Government than a dollar of potential savings to be realized in the future. Thus, the Government should expect more than a dollar back for every dollar that it spends on competition. To take this into account, the estimated savings and costs from competition have been discounted and compared in column 6 of Table 5.[3] While the ratios of estimated savings to incremental costs are substantially reduced by discounting, they still remain greater than one.

These ratios should be viewed with some caution because they are based on uncertain estimates of what UPC growth would have been in the absence of competition. For example, a 95 percent confidence interval would permit estimates of the median UPC growth rate for the noncompetitive programs to vary from 2.9 to 9.1 percent, as opposed to the 5.8 percent assumed

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[1]Based on the truncated December 1982 program, ALCM savings are estimated at only $270.1 million (in constant 1977 dollars), and thus are less than the incremental costs. In escalated dollars, the estimated savings are 1.4 times as great as incremental costs.

[2]In escalated dollars, the estimated savings are $1.320 billion for the M-1, $1.168 billion for the M-247, and $1.231 billion for the AGM-86B.

[3]As specified in OMB Circular A-94, this study uses a ten percent discount rate.

above.[1] If 2.9 percent were the median noncompetitive UPC growth rate, the discounted savings/cost ratio would be one or greater only for the M-247 competition. With this reservation in mind, however, the savings/cost ratios do suggest that R&D prototype competition can more than pay for itself in procurement cost savings in certain cases.

C. TERMINATION POINT FOR R&D COMPETITION

- At what point within the R&D phase does it appear from these data that competition should be terminated?

The overriding concern is that the competition should be carried far enough that the contractors can prudently propose production options with competitively determined price ceilings. As R&D competition is carried further, contractor risks can be reduced and the price ceilings can be made more comprehensive in terms of the procurement cost categories covered as well as the production quantities and the number of years included. At a minimum, competition should be carried to the point where fully integrated prototype systems have

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[1]The confidence interval was determined based on the quantile test as described in W.J. Conover, "Pra tical Nonparametric Statistics," p. 110-115.

been tested and considerable attention has been paid to producibility and production planning.[1]

Paper competitions are clearly inadequate from the point of view of controlling procurement costs. Without prototype testing, it cannot be known whether a proposed design concept will work, let alone what it would cost to produce. Thus, choosing between paper proposals on the basis of procurement cost estimates would be a hazardous undertaking. Indeed, the case studies indicate that cost-reducing innovations can be controversial and might well be rejected on the basis of paper proposals alone. Hughes' lightweight airframe approach, Ford's use of the proximity-fused (PX) round and Boeing's adoption of net-shape casting for its fuel tank were all controversial, cost-reducing ideas that were accepted by the Government only after prototype testing demonstrated that they worked. These three winners might well have been losers if their respective source selections had been based on paper proposals alone.

Prototype competitions that do not result in competitively priced production options provide some potential for procurement cost savings. Prototype fabrication provides cost

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[1]In James A. Evans, "Potential Adverse Effects of Competitive Prototype Validation," the following statement is quoted from a study at the Logistics Management Institute:

> Parallel development [should be] carried on until three conditions are satisfied. First, the contractors must know enough about their designs to assess accurately the risk they would be embracing in proposing to complete the program on a fixed-price basis. Second, the Service must know enough about the designs to select the best alternative, price and all other factors considered. Third, the Service must be able to assess the risk being assumed by the contractors and independently determine that it is reasonable for the contractors to assume that degree of risk.

information and prototype testing validates design concepts, so that the Government has a reasonable chance of determining which system would cost less to produce. Thus, contractors can be motivated to take design-to-cost goals seriously, as occurred in the M-1 Program even before the requirement to propose price ceilings was established. But while cost-reducing design features, such as Hughes' lightweight airframe, may be built into the design during a competitive phase and hence survive a sole-source follow-on development phase, the winning contractor has little motivation to continue cost control efforts during the critical transition-to-production phase without a firm, competitively determined production price commitment. A ceiling price requirement can motivate competitive contractors toward even more intensive efforts to control UPC during a competitive design phase, to agree to greater profit risks (or lower profits) than they would accept in a sole-source production price negotiation, and to continue a vigorous effort to control UPC as the design matures in the follow-on phase and as production is initiated. In addition, priced options can delay the first sole-source production negotiations until the Government has some actual production cost data to support its negotiating position.[1]

The M-1 Program demonstrated that competitive contractors can be persuaded to propose firm ceiling prices for production that will not even be initiated until two and one-half years after the proposal is accepted. The M-1 competition included fully integrated prototypes, thorough design-to-cost (DTC)

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[1]That is, the ceiling prices motivate the contractor toward production efficiency and the Government can then insist on a continuation of the same learning curve.

estimates and reviews and some amount of production planning so that the contractors had a reasonable basis on which to formulate their proposed prices. Further, the contractor is expected to make some profit on its initial production contract. Thus, a competitive advanced development (AD) program ending with priced proposals is a viable alternative. However, contractor cost risks are hign when production is delayed that much (i.e., for two and one-half years) and that can limit the number of options, the quantities, and the aspects of the procurement program for which AD competitors would be willing to propose firm ceiling prices. Thus, while estimated savings exceeded the incremental costs of the M-1 competition, potential savings were lost because its ceiling prices did not include Government facilitization costs, initial spares and repair parts, or support hardware. In contrast, the first production option for the Sgt. York was exercised one year after the proposal was accepted and covered virtually all procurement aspects. The Sgt. York competitors submitted priced proposals covering 45 percent (versus 6.5 percent for the M-1) of the total quantity and three (versus two for the M-1) production option years. The ALCM proposals covered two years of production and 21 percent of the then-planned total quantity, and production was initiated at the time the Boeing proposal was accepted. The ALCM price ceilings included operational support hardware as well as the missiles themselves, and a ceiling was also established for Government-funded production tooling. Thus, it is evident that contractors are willing to propose more comprehensive price ceilings the more production-ready the competitive prototypes are.

Extending competition through full-scale engineering development (FSED) up to the point of production, however, can be very expensive. The Sgt. York FSED costs were unusually low due to the extensive use made of mature components requiring relatively little modification. In contrast, the ALCM FSED costs were relatively high. This resulted, in part, because the developers could count on reusing only some of the prototype missiles during the ten FSED test flights, thus increasing the number of FSED prototypes required.[1] ALCM costs were also high because the competition included pilot production of 24 missiles by each competitor, accounting for 27 percent of the cost of the competitive phase. While the pilot production contributed to the evaluation of prospective production costs, it was also instituted so that the first B-52 equipped with 12 ALCMs could go on alert status by the early date of September 1981. Of the four case studies, growth in unit procurement cost (UPC) was lowest for the two systems that carried competition through FSED. Despite the high cost of even the ALCM competition, its estimated savings exceeded its incremental costs (on a constant-dollar, discounted basis and prior to truncation of the production program).

In summary, R&D prototype competition appears to lead to increasing benefits the closer toward production it is extended. Instrumental in this pattern is the fact that contractor cost risks decline as a system approaches production, enabling the Government to increase the scope and size of its requirements for priced production options.

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[1]For example, Boeing constructed 12 FSED prototypes for the ALCM, while Ford constructed only two prototype systems in the Sgt. York competition.

D. SELECTING PROGRAMS FOR R&D PROTOTYPE COMPETITION

- What economic criteria would assist in judging the desirability of R&D competition for particular systems?

A strictly economic decision should be based on a comparison of the incremental costs of the specific prototype competition with the potential savings in procurement costs. If the estimated savings are not as great as the incremental costs on a constant-dollar, discounted basis, then competition could not be justified on the basis of procurement cost savings alone.

Comparing estimated savings and incremental costs would indicate that prototype competition should be used when R&D costs are particularly low (e.g., if substantial use can be made of mature components) or if procurement costs are relatively high. Since the incremental costs and estimated savings should be discounted, the comparison will also tend to favor competition for programs where the production build-up is particularly rapid and the overall production schedule is relatively short, so that potential procurement savings can be realized relatively early.[1]

The data of this study do not permit an adequate estimate of what procurement cost savings should be expected when prototype competition is employed. Based on the median annual UPC growth rates for the competitive and noncompetitive programs discussed in Chapter III, UPC would have been 15.5 percent higher if it had grown at the 5.8 percent median rate of the noncompetitive programs rather than the 3.1 percent

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[1]A program that builds up to rate production quickly may present greater cost risks, another reason to consider R&D competition with firm price ceilings.

rate of the competitive programs (over the seven-year duration of the median SAR program). However, the 95 percent confidence interval for the difference in medians is quite wide, and would permit this savings estimate to vary from -12.7 percent up to 28.8 percent. For the four case studies, the estimated savings are:

- AH-64: -
- M-1: 7.3 percent
- M-247: 30.7 percent
- AGM-86B: 18.3 percent.

Thus, while the data indicate that procurement cost savings from prototype competition can be substantial in certain cases, there is too much variation to permit an estimate of what savings should be expected in general.

The savings assumption appropriate for a particular program that is a candidate for prototype competition would depend, in part, on its planned program structure. That is, it would vary depending on the development stage (i.e., AD or FSED) at which the competition would terminate, how fully integrated the competitive prototypes would be, whether priced production options would be required, how comprehensive such priced options would be in terms of quantities, years, and cost categories to be included, and whether competitive pilot production was to be included.

A number of other factors should be considered in assessing the potential savings from competing a particular program. These factors, bearing on the risk of procurement cost growth and the opportunity to control such growth through competition, include:

- Technical Risk. High technical risks, due to the necessity of developing new technology or of pushing existing technology to the limit to meet demanding performance requirements, also mean high cost risks. In such cases, procurement costs can be especially difficult to estimate in advance, and there is a greater risk of procurement cost growth as engineering changes are grafted onto an increasingly firm design or retrofit onto initial production. Thus, high technical risks indicate that special efforts at cost control, such as prototype competition, are needed. On the other hand, high technical risks present certain difficulties to the use of prototype competition. High technical risks increase the likelihood that the savings due to competition will be lost if one of the competitors cannot develop a successful prototype in the time allotted (leaving the remaining contractor in a sole-source position to bid on the follow-on contracts) or if design changes after the competition invalidate the savings embedded in the competitive prototype designs.

- Component Maturity. A program that largely develops its own subsystems may present a greater opportunity for procurement cost savings through competitively motivated design to-cost (DTC) efforts (since there is more scope for design flexibility). But competitive R&D costs for such a program are also higher (compared to a program relying more on mature components). In addition, a program relying more on mature components can concentrate on producibility modifications since the component designs from a performance point of view are relatively firm.

- Concurrency. If the development schedule is relatively short and forces the program to include substantial concurrency between development and production, the risk of cost growth will tend to be higher. The design may be firmed and prepared for production based on less than normal early testing, thus making later design changes and production retrofits more likely. A competitive program requiring a competitively priced provision for the correction of design deficiencies could be particularly effective in such a case. But concurrency can also increase the cost of prototype competition since orders for long-leadtime items and even pilot production may occur earlier than usual in the development cycle.

- Program Stability. It might be prudent to avoid investing in prototype competition if a program has an unusually high chance of cancellation. In addition, it is possible that even a sole-source development contractor would be motivated to control expected procurement costs if funding problems were the reason for the program being on shaky ground. On the other hand, using prototype competition in such a case might lead to sufficient procurement cost savings to save the program from cancellation.

- Requirements Stability. Procurement cost savings in a competitive prototype design may be lost if later changes in the Service's functional requirements force major changes in the design. Such changes could also invalidate the price savings embedded in competitively negotiated production options.
- Company Characteristics. Competition would be more likely to impact procurement costs in a case where the likely sole-source contractor(s) has (have) a reputation for designing costly systems or for inefficient production. Competition, however, might have little impact unless sufficient competent firms are available to provide a credible match up.

This discussion has centered on the circumstances under which prototype competition would tend to pay for itself through savings in eventual procurement costs. A decision to employ prototype competition would also take into account other potential benefits, such as improved performance, reduced schedule risks, or lower life cycle costs.[1]

[1]For the four case studies, performance was still as important as cost in the source selections, and the winners all evidenced certain performance advantages over their rivals. All the contractors were competitively driven to meet the schedules established for competitive testing (although there were some delays) and the abilities of the contractors to meet compressed production start-up schedules was important to source selection for three of the four programs. Support cost advantages also played an important role in discriminating between the competitive proposals.

CHAPTER VI

CONCLUSIONS

The four questions that were posed in the introduction and discussed in Chapter V can be answered as follows:

- Does prototype competition during the R&D phase result in lower production costs?

R&D prototype competition, on average, does lead to lower production costs than would be incurred without such competition. The extent of such savings, however, depends importantly on how the competitive program is structured.

- Do these downstream savings compensate adequately for the incremental, up-front costs of using competition?

Procurement cost savings are estimated to exceed the incremental costs of competition for three of the four case study programs, even after eliminating the impact of inflation and taking into account the time value of money.

- At what point within the R&D phase does it appear from these data that competition should be terminated?

The overriding concern should be to carry competition far enough that the contractors can prudently propose production options with competitively determined price ceilings. At a minimum, competition should be carried to the point where fully integrated prototype systems have been tested and considerable attention has been paid to producibility and production planning. As R&D competition is carried further, contractor risks can be reduced and the price ceilings can be made more comprehensive.

- <u>What economic criteria would assist in judging the desirability of R&D competition for particular systems?</u>

A new system should be considered for R&D competition if the incremental cost of a well-structured competitive program would be less than the estimated potential savings in procurement costs, on a constant-dollar, discounted basis.

In summary, the data considered in this study indicate that prototype competition is a valuable tool for the control of procurement costs. It is not the only such tool, it would be too costly to use for some programs, and there is no guarantee that it would be effective in every case. For many programs, however, a well-structured prototype competition has the potential to pay for itself through procurement cost savings. Also, a substantial bonus may well be available by way of improved performance, reduced schedule risk and lower operating and support costs.

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Appendix A

AH-64 APACHE ATTACK HELICOPTER SYSTEM

APPENDIX A

AH-64 APACHE ATTACK HELICOPTER SYSTEM

A. INTRODUCTION

The AH-64 Apache Attack Helicopter System was developed under a two-phase program. Phase 1 was a competitive engineering development program for the air vehicle while Phase 2 encompassed the sole-source integration of mission subsystems and support items. Firm ceiling prices for future production contracts were not established during the Phase 1 competition. Further, a number of factors led to substantial growth in unit procurement costs during Phase 2. The question is thus raised as to whether such a competition can lead to a design that is inherently less costly to produce and whether such benefits can be preserved during an extended sole-source development phase.

The AH-64 discussion is organized as follows:

- Section B provides background information on the weapon system, its program history and its acquisition strategy;
- Section C discusses the incentives to control procurement costs provided by the structure of the competition;
- Section D assesses the potential procurement cost benefits of the Phase 1 competition and analyzes Phase 2 growth in unit procurement costs;
- Section E presents concluding remarks.

B. BACKGROUND

1. Mission and System Description

The AH-64 Apache Attack Helicopter was developed for the primary mission of defeating tanks.[1] Additional roles include providing suppressive fire during escort or air cavalry assault operations.[2] The AH-64 will be assigned at the corps level and will operate in the forward battle area. Its mobility (relative to ground forces) will enhance the ground commander's ability to mass firepower to counter enemy armored breakthroughs, to take advantage of target opportunities, and to adjust quickly to changing needs for close air support. The AH-64 can be responsive over a broad front despite rugged terrain obstacles. Thus, in conjunction with other ground and air antitank weapons, the Apache is intended to offset the numerical superiority of Soviet tanks.

In fact, the Apache can use terrain obstacles to its own advantage. It has been optimized for agile, low-level, nap-of-the-earth flying (even at night or under adverse weather conditions) so that it can hide behind terrain features as it moves about the battlefield as well as stay beneath the effective range of radar-directed enemy air defense missiles. The Apache is designed to hover behind available defilade, pop up to deliver its ordnance, and then drop down

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[1]This discussion is based on Army statements at Congressional hearings during the past ten years. See, for example, Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4933-4943.

[2]The primacy of the antitank role was demonstrated in 1981 when a budgetary reduction in the projected production quantity primarily affected air cavalry rather than antitank units. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, page 471.

to move laterally to a new position. The AH-64 has not been designed to penetrate enemy territory but, since battle lines may be fluid, major design emphasis has been placed on survivability from hostile fire. In addition, the Apache is intended to operate in a combined arms environment wherein enemy air defense would be suppressed by means of fire from artillery and fixed-wing aircraft. Survivability is also enhanced because the antitank missile can be fired effectively from a stand-off position beyond the range of enemy air defense guns.[1] The AH-64, however, has only limited defensive capability against other aircraft.[2]

The Apache is viewed by the Army as a complement to the A-10 fixed-wing aircraft that was developed by the Air Force for the antitank and close-air-support missions.[3] The A-10 is faster, more maneuverable, with greater range, an outstanding antitank cannon, and heavier ordnance capacity. It would be used to strike priority targets over a wide area including penetration behind enemy lines. The AH-64, on the other hand, is more effective at nap-of-the-earth flight, can loiter safely (behind terrain features) near the front in order to respond quickly to needs as they develop, can hover to provide a stable platform for laser-guided antitank missiles, is

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[1]The Soviet ZSU-23-4 air defense gun is said to have a maximum effective range of 2.5 kilometers. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1981 Appropriations, Part 9, June 3, 1980, page 39.

[2]While the AH-64 has not been optimized for defense against other aircraft, the Chain Gun and Hellfire can be used in that role. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, page 384.

[3]See, for example, Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5068, Part 3, February 4, 1977, page 216.

equipped for operation at night and under adverse-weather conditions, and has more flexible basing requirements. Thus, the AH-64 provides distinct capabilities and is more closely integrated with ground forces.[1]

The AH-64 is armed with a 30mm Chain Gun and with 2.75-inch rockets for suppressive fire and to destroy soft targets. The principal armament, however, is the Hellfire antiarmor missile. The Hellfire carries a lethal seven-inch warhead and is said to have a range exceeding seven kilometers.[2] The Hellfire homes to its target on a coded laser beam that must track the target until missile impact. The AH-64 carries its own target designator but can also launch Hellfires to be directed to their targets by laser designators on the ground or in scout helicopters.[3] When the AH-64 is not required to designate its own target, it can pop up, launch a Hellfire, and then immediately drop down behind cover. If the Apache is far enough behind its covering terrain obstacles it can launch a Hellfire without even popping up and exposing itself to hostile fire. The Apache carries a sophisticated target acquisition/designation sight (TADS) to provide precision target acquisition and tracking at

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[1] As a result of Army/Air Force agreements in 1948 and 1966, the close-air-support role is addressed with fixed-wing aircraft by the Air Force and with rotary-wing aircraft by the Army. There has been considerable interservice controversy over who should provide close air support. See, for example, Gregg Easterbrook, "All Aboard Air Oblivion," page 15-22.

[2] See Aviation Week and Space Technology, May 30, 1977, page 14.

[3] The Army's plans to develop a new scout helicopter have been delayed. Instead, OH-58 light observation helicopters are being rebuilt for the scout role under the Army Helicopter Improvement Program (AHIP). For a discussion of AHIP, See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, page 495-509.

the extended Hellfire ranges, at night and during adverse weather conditions. The TADS is mounted on a stabilized platform and includes a laser range finder/designator, a special television camera, a forward-looking infrared sensor (FLIR), and direct-view optics. In addition, there is a capable pilot night vision sensor (PNVS) utilizing its own FLIR and other sensors to provide visual and symbolic flight control information to a one-inch screen slaved to the pilot's helmet. It is the PNVS that enables the pilot to fly the AH-64 a few feet above rough terrain at night or in adverse weather.

Because a helicopter's flight tends to be low and slow, it is particularly vulnerable to enemy ground fire. The tactics discussed above (i.e., nap-of-the-earth flight and stand-off missile firing) are intended to reduce the AH-64's exposure to hostile fire. In addition, major emphasis has been placed on enhancing survivability in the face of exposure to enemy air defense fire. To avoid being hit, the AH-64 includes reduced visual, aural, infrared, and radar signatures; radar warning devices; and radar and infrared jammers. To avoid crashing following a direct hit, the Apache incorporates armor protection for the crew and critical components, redundant flight controls, and spaced-out stringers and formers in the fuselage. The AH-64 is fully protected against 12.7mm hits and, to a large extent (including the main rotor blades), against 23mm hits.[1] There are twin engines and continuing flight capabilities in the event one engine is damaged. The Apache has also been

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4045.

designed to minimize damage and crew loss in the event that it does crash.

2. The Cheyenne Program

The present Advanced Attack Helicopter (AAH) Program was initiated with the cancellation of the Lockheed AH56A Cheyenne development program.[1] The Cheyenne Program had been initiated in 1963 and Lockheed's development contract was awarded in March 1966. Approximately $400 million had been spent and the Cheyenne's development was nearly complete by 1972.[2]

The Cheyenne was the first Army helicopter designed from the start as a weapons platform.[3] Major emphasis was placed on its intended role of escorting helicopter convoys (in addition to providing direct fire support to ground forces). As a result, the Cheyenne required high air speeds (over 200 knots) that challenged the state of the art for helicopter flight. The resulting design was a compound fixed-wing/rotary-wing aircraft with a ten-foot pusher propeller and an innovative rigid main rotor system, all intended to permit the required speed. The Cheyenne subsystems included a sophisticated navigational capability and a computer-based fire control system to integrate its cannons, rockets, and TOW

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[1] For a brief history of the Cheyenne Program, See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 155-157. See also Committee on Armed Services, House of Representatives, Hearings on Cost Escalation in Defense Procurement Contracts and Military Posture and H.R. 6722, Part 3, May 9, 1973, page 2972-3 and Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4115-4116.

[2] See Aviation Week and Space Technology, August 14, 1972, page 21.

[3] The AH-1G was an interim attack helicopter derived from the Bell UH-1 utility helicopter for use during the Vietnam War.

missiles. The Cheyenne had actually been in initial production when a test vehicle crashed in March 1969 due to control problems associated with the rigid rotor system. Production was then cancelled so that a new mechanical control system could be developed. By 1972, an interim control system had proved adequate under overload conditions up to 20,500 pounds and an advanced mechanical control system had been designed that would be adequate up to the desired 22,500 pounds. The Army assessed the Cheyenne as follows:

> Its R&D results to date, both as a flying machine and as a fighting machine that shoots different armaments, have been excellent. It is clear it will work well.[1]

But while the Cheyenne in 1972 appeared to be a technical success, the Army was concerned about its high unit cost. The Army recognized:

> ... in 1971 and 1972 that helicopters cost a lot more than we had thought they were going to cost in 1963.[2]

The production decision was held up and a producibility/cost reduction program was instituted to reduce unit costs by 10 percent.[3] Proposed cost reductions included deleting some complex navigational gear and utilizing a more modern computer.

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 12604, Part 3, February 22, 1972, page 11076.

[2] See Committee on Armed Services, House of Representatives, Hearings on Cost Escalation in Defense Procurement Contracts and Military Posture and H.R. 6722, Part 3, May 9, 1973, page 2972.

[3] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 12604, Part 3, February 22, 1972, page 11067.

At the same time, the Army began to question what kind of attack helicopter it wanted, in light of survivability problems in the new mid-intensity threat environment as well as the high cost of the Cheyenne. In January 1972, the Army convened a task force to re-examine its AAH requirements.[1] Survivability tests were conducted at Hunter Liggett Army Airfield in California. Previous helicopter experience was analyzed, especially the extensive experience in Vietnam.[2] Survivability tactics were tested in Germany in exercises involving West German, Canadian, and US Forces.

From this reevaluation process emerged new AAH tactics and system requirements. Survivability would be best served by a helicopter optimized for low-speed, nap-of-the-earth flight. What was required was an agile, controllable helicopter with extensive survivability features and an efficient hovering capability. From March until May 1972, the Army conducted flight tests of the Cheyenne, the Bell King Cobra (an improved version of the AH-1G) and the Sikorsky S-67 (based on the CH-3). It was determined that none of these helicopters would adequately meet the Army's new AAH requirements.[3] The Cheyenne had been optimized for speed rather than agility or hovering efficiency. Further, it was too expensive, in part, because its integrated fire control and navigational precision went beyond the Army's minimal needs. Accordingly, in August 1972, the Army cancelled the

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[1] See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 156.

[2] Between May 1972 and January 1973, two UH-1Bs experimentally equipped with TOW missiles defeated 27 North Vietnamese tanks. See Aviation Week and Space Technology, May 14, 1973, page 15.

[3] See Aviation Week and Space Technology, August 14, 1972, page 21.

Cheyenne Program and announced plans to initiate a new AAH development program.

While the new AAH was being developed, the Army would equip Bell AH-1Q Cobras with TOW missiles to provide an interim antitank capability.[1] But the Cobra had inherent airframe and power limitations that prevented its modification to meet the AAH requirements.[2] The Cobra's maximum gross weight was 10,000 pounds (versus 17,650 pounds for the AH-64). The Cobra was powered by a single engine with a shaft horsepower of 1800 (versus twin engines with shaft horsepowers of 1690 each for the AH-64). The Cobra carried a 7.62mm (rather than a 30mm) gun and was armored against 7.62mm (rather than 12.7mm and 23mm) shells. The Cobra's level speed was slower, its hovering inadequate, and it was not equipped with night vision or adverse weather instrumentation.[3]

3. Acquisition Strategy

Following cancellation of the Cheyenne Program, the Army immediately initiated its effort to develop a new advanced attack helicopter (AAH). After some revision of its original plan, the Army obtained DSARC approval for a Phase I development program in November 1972 (as indicated on Table A-1). The Army received development proposals from five companies in early 1973, and awarded competitive development

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[1]Present plans call for continued use of the latest Cobra version as a supplement to the AH-64.

[2]See Committee on Appropriations, US Senate, Hearings on Fiscal Year 1975 Appropriations, Parts 2-3, March 12, 1974, page 494.

[3]See Aviation Week and Space Technology May 14, 1973, page 16.

Table A-1. CHRONOLOGY OF EARLY AAH EVENTS

DATE	EVENT
March 1966	Cheyenne development contract awarded to Lockheed.
March 1972	T700 engine development contract awarded to General Electric (for UTTAS program).
August 1972	DSARC I approves AAH development program.
June 1973	Phase 1 development contracts awarded to Hughes and Bell.
Sep./Oct. 1975	Hughes and Bell prototypes experience first flights.
February 1976	ASARC directs use of Hellfire missile on AAH.
July 1976	Competitive DT/OT begins.
September 1976	Competitive DT/OT completed.
December 1976	Hughes selected and DSARC II approves Phase 2 development program.

contracts to Hughes Helicopters and Bell Helicopters in June 1973.

From the beginning, the AAH Program had an extremely high priority within the Army. The Army has characterized it as being:

> ... among the very highest priority Army combat developments which, along with the XM-1, is essential if U.S. forces are to counter the current four to one imbalance in tanks which exists between Warsaw Pact and NATO forces.[1]

As noted above, the new AAH would de-emphasize the escort role of the Cheyenne so that air speed requirements could be reduced from over 200 knots to a minimum of 145 knots. To support the Army's new AAH tactics, the new aircraft would be optimized instead for hovering, agility, nap-of-the-earth flight, and survivability. The AAH requirements, however, were also defined with a view toward avoiding the high costs of the Cheyenne. The maximum average recurring flyaway cost was set at $1.6 million (in 1972 dollars) substantially below the approximately $2.7 million flyaway cost expected for the Cheyenne.[2] Reduction of the air speed requirement was expected to have an important impact on reducing complexity and production costs. In addition, the new AAH would be 2000 pounds lighter[3] and its navigation and fire control requirements would be less demanding. The AAH was to be a

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4109.

[2]See Aviation Week and Space Technology, May 14, 1973, page 15.

[3]See Aviation Week and Space Technology, October 23, 1972, page 16.

"bare-bones aircraft with performance."[1] Finally, unlike the Cheyenne, the new AAH would not challenge the state of the art for helicopter flight. According to the AAH program manager:

> From its inception, the AAH program has been based on a premise that technical risks in the development program must be kept to a minimum. The concepts and design philosophies, together with the equipment requirements, have all been assessed to be within (the) current state of the art.[2]

The decision to employ competition during the AAH development program was based, in part, on a current OSD attitude favoring competition.[3] In addition, the Army hoped to learn from its Cheyenne experience and find more effective ways to control costs. The Director of Army Aviation observed:

> Selecting two contractors will result in competition that should drive the cost down. The initial costs for development will be larger, but this should be offset during the procurement cycle.[4]

Nevertheless, the Army did reserve the right to utilize a single developer if its proposal (for Phase 1) were clearly superior to the other proposals received.

The AAH development was to be divided into two phases. The Army would solicit proposals specifying completely integrated AAH systems and would select two companies for a competitive Phase 1 development effort. Phase 1, however,

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[1]See Aviation Week and Space Technology, March 26, 1973, page 51.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4982.

[3]See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 159.

[4]See Aviation Week and Space Technology, May 14, 1973, page 15.

would concentrate on the air vehicle, and mission-oriented subsystems would be integrated later in a sole-source Phase 2. This division of labor was adopted because most subsystem components were considered already developed and the greatest technical and cost risks were thought to be associated with the air vehicle.[1] Accordingly, deferring subsystem integration seemed a prudent way of reducing the higher R&D costs of competitive development. At the same time, it was felt that a two-phase approach would enable the Army to take further advantage of the rapidly advancing state of the art in electronics (to reduce cost and enhance performance).[2]

During Phase 1, each competitor was to design, fabricate and test two flyable prototypes and one ground test vehicle. The prototypes were to conform with military specifications and the Phase 1 effort was considered to be engineering (rather than advanced) development in light of the proven technologies to be employed.[3] Testing would emphasize handling and performance characteristics of the air vehicle. While the prototypes would be austere, specific provisions would be made for the space, weight, and power requirements of the subsystems to be integrated in Phase 2. In addition, the (unintegrated) 30mm cannons would be test fired in order to determine their impact on the airframe structure and on flight

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[1] See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 159.

[2] See Committee on Armed Services, House of Representatives, Hearings on Cost Escalation in Defense Procurement Contracts and Military Posture and H.R. 6722, Part 3, May 9, 1973, page 2974.

[3] See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 160.

characteristics.[1] Plans also called for test firing of the TOW missiles and 2.75-inch rockets. Phase 1 would culminate in a four-month combined development test/operational test (DT/OT) to provide data for validating and evaluating the contractors' proposals for the Phase 2 effort. During the sole-source Phase 2, three additional prototypes would be fabricated and the mission subsystems would be developed, integrated, and tested. Subsystems to be added included the weapons and fire control systems as well as navigation, communications, and night vision equipment.

The AAH Program was among the earliest major systems to utilize an explicit design-to-cost approach. The design-to-cost (DTC) goal was specified as an average, recurring flyaway cost of from \$1.4 to \$1.6 million (in constant 1972 dollars) per system for a procurement of 472 AAHs at a maximum rate of eight per month. The companies were instructed to propose DTC goals within the specified range and then, in Phase 1, to design systems that met their proposed goals. Further, the Army wanted to provide the competitors with sufficient design flexibility so that they would have a realistic chance of achieving their DTC goals:

> We therefore recognized that there was a distinct possibility that we could not get all we wanted to get in this attack helicopter for that price. So, for many of the performance characteristics we established a lower threshold which represented less performance than we desired. Then, we said, "Within the band between the threshold below which we don't want you to go and the figure which describes what

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4696.

we would like to attain, you may trade off performance in the interest of reducing costs."[1]

With such flexibility, the DTC goal could serve as a design parameter as well as a management threshold.[2] The contractors were required only to notify the AAH Program Management Office (PMO) when they made trade-offs (i.e., reductions below their proposed performance levels) above the lower limits. Trade-offs below the lower limits would be possible if justified but would require prior PMO approval. The four major performance goals were:

- cruise air speed, 145 to 175 knots,
- vertical rate of climb, 450 to 500 feet per minute, (at 4000 feet on a 95½F day utilizing 95 percent of engine rated power),
- primary mission payload, 8 to 12 TOW missiles and 800 to 1000 30mm rounds,
- primary mission endurance, 1.9 hours.[3]

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[1] See Committee on Armed Services, House of Representatives, Hearings on Cost Escalation in Defense Procurement Contracts and Military Posture and H.R. 6722, Part 3, May 9, 1973, page 2974.

[2] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4982.

[3] See, for example, Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4970.

The competitive nature of Phase 1 would provide a motivation for the contractors to meet the DTC goal and still develop systems with adequate performance.[1]

4. Conduct of Competitive Development

In June 1973, Phase 1 development contracts were awarded to Hughes and Bell. The recurring unit flyaway cost for the Hughes proposal was slightly above $1.4 million and for the Bell proposal slightly above $1.5 million.[2] There was a wide disparity in the Phase 1 R&D costs proposed by the two firms. The Hughes award was expected to cost $70.3 million (in then-year dollars) as compared to $44.7 million for Bell.[3] A number of explanations have been offered for the difference in R&D cost proposals:

- Hughes planned a greater effort to reduce aircraft weight,
- Hughes developed its own 30mm gun system,
- Hughes relied more on subcontractors,
- Bell had more ability to spread its costs to other military contracts (e.g., the Cobra),
- Bell was reacting to losing in the recent UTTAS competition, possibly as a result of an high R&D cost proposal.

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[1] In their proposals for Phase 1, the five firms were thus free to vary both unit cost and performance in configuring systems that provided the best overall value for the Government. This flexibility was retained to a large extent during the execution of Phase 1, although an incentive fee was available for actually achieving the design-to-cost (DTC) goals.

[2] See Aviation Week and Space Technology, July 2, 1973, page 17.

[3] See Aviation Week and Space Technology, July 2, 1973, page 17.

The Phase 1 contracts were cost-plus-incentive-fee (CPIF) contracts.[1] Cost growth was substantial, with Phase 1 costs eventually rising to $99.2 million for Hughes and $75.4 million for Bell. The AAH Program experienced cost overruns in FY75 and FY76, due to unanticipated inflation and to technical development problems.[2] As a result of the FY75 overrun, the Phase 1 program was extended from 36 to 42 months. Overruns may also have contributed to the deletion of funds (by Congress) from the FY76 request that would have been used for long-leadtime items for the Phase 2 prototypes. This deletion extended the planned Phase 2 by five months.

Phase 1 was managed in many ways like a standard engineering development program. For example, the PMO received normal monthly cost and schedule information and met with the contractors in order to control Phase 1 costs. As noted above, however, the contractors were accorded unusual design flexibility and retained configuration management control. The PMO monitored design changes but avoided comments that would assist one contractor over the other.[3]

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, pages 4706-4707, for a discussion of the use of CPIF versus fixed-price-incentive (FPI) contracts. The CPIF contract may encourage competitive contractors to increase R&D costs in order to gain competitive product advantages. This places a greater burden on the PMO to try to control costs and to do so in a way that is fair to both contractors. FPI contracts, however, would not necessarily cost the government less and, if they did, could hurt system design by unduly restricting contractor flexibility.

[2] See Committee on Appropriations, US Senate, Hearings on Fiscal Year 1977 Appropriations, February 23, 1976, pages 2-3.

[3] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, Pages 4980-4981.

Both contractors conducted eight months of flight testing prior to the Army's DT/OT.[1] They were largely free to design their own contractor test programs while the PMO provided some direction and closely monitored the tests.[2] While both contractors identified technical problems during their test programs, the Army reported that the engineering problems were under control prior to the DT/OT.[3] On May 31, 1976 the contractors presented their prototypes for training of Government pilots for the DT/OT. Hughes delivered its aircraft to Edwards Air Force Base on June 14, 1976. One of the Bell prototypes, however, crashed during pilot training (as a result of previous, undiscovered damage to the prototype) and the remaining flight prototype was not delivered to Edwards until July 10, 1976. At the same time, Bell began to convert its ground test vehicle for flight and was able to deliver it to Edwards by August 2, 1976. As a result of the Bell crash and certain Hughes problems, the DT/OT did not begin until July, about a month late. Nevertheless, all programmed tests and flight hours were completed on schedule by September 30, 1976 so that the source selection evaluation was not delayed.[4] The contractors submitted technical and management proposals for Phase 2 by July 31, 1976 and cost proposals by August 15, 1976. The

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[1]Discussions at Hughes suggest that this was a relatively short test program for proving out a new design.

[2]See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 165.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4697.

[4]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4048.

source selection board evaluated the test data and challenged the details of the Phase 2 proposals. Best and final offers (BAFOs) were received by November 22, 1976 and Hughes was selected by early December.

C. COMPETITIVE INCENTIVES TO CONTROL COSTS

1. Value of Winning

The rewards for winning the competition during Phase 1 promised to be substantial. The immediate prize would be an engineering development contract for Phase 2 initially priced at $317.6 million (in then-year dollars).[1] This contract would place the winner in a sole-source position for later negotiations for production contracts in a procurement program now estimated to cost over $6 billion.[2] In addition to the direct profits possible under these contracts, the work would build (in the case of Hughes) or maintain (in the case of Bell) the engineering and production capabilities of the firms and would permit possible commercial spin-offs and foreign military sales.[3] Other contractors had already been selected for the Army's other major helicopter program, the UTTAS, making the AAH contract that much more important. Bell considered the program to be so important that they gave their AAH manager "more authority than any one man has ever had at

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[1]See Aviation Week and Space Technology, January 3, 1977, page 17.

[2]Based on Selected Acquisition Report (U), December, 1982. SECRET. Information derived for this report is Unclassified.

[3]For example, the Federal Republic of Germany has considered purchasing as many as 150 AH-64 Apaches. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, page 462.

Bell to conduct a project...."[1] as well as "priority access to company assets...."[2] As discussed below, Hughes Helicopters and its AAH Program were virtually the same thing.[3] Thus, there is ample reason to believe that both contractors were highly motivated.

2. Credibility of Competitors

Did Hughes and Bell have good reason to view each other as credible competitors? Clearly Bell should have been viewed as a formidable competitor. Bell had begun building the UH-1 helicopter in the 1950s and was still producing both new and modified versions of the AH-1 Cobra Attack Helicopter. Bell was a solid company (a division of Textron) and an experienced producer, with the facilities and expertise to do much of the prototype design and fabrication work in-house. Hughes, however, was a smaller company with relatively little in-house capability to construct a medium-size helicopter.[4] Hughes was forced to subcontract the fabrication of most major components, including the fuselage. Hughes (then a division of Hughes Tool Company) had designed and built 1415 OH-6A light observation helicopters (LOHs) during the mid-sixties, but lost a follow-on competition for 2200 additional LOHs to

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[1]See Aviation Week and Space Technology, July 2, 1973, page 17.

[2]See Aviation Week and Space Technology, June 9, 1975, page 35.

[3]Discussions at Hughes indicate that employment has grown from (approximately) 750 to 5500 since the beginning of the AAH Program. To a large degree, winning the competition was a make-or-break proposition for Hughes.

[4]At the time of the Phase 1 award, Hughes was producing some Model 300 and Model 500 helicopters for the commercial market, as well as parts for the OH-6A, and ordnance.

Bell Helicopters in 1968.[1] The OH-6A was a relatively simple, light aircraft and Hughes' LOH experience was not entirely relevant to developing and producing a medium-size attack helicopter:

> Hughes designers drew heavily on the experience with the OH-6 in the Vietnamese battlefield environment when making basic decisions about the YAH-64 configuration. But the AAH prototype represents a larger and more complex helicopter than the company has ever built.[2]

Further, Hughes' management capabilities were suspect:

> Hughes has not built anything this large and complex before. Quite frankly, it has been run as something of a hobby shop under the former owner, without recognizing profits and management efficiency as the usual measures.[3]

Thus, Bell would have had some reason to doubt Hughes' credibility as a competitor.

Once the Phase 1 contracts were awarded, however, Bell could not have afforded to dismiss Hughes' chances altogether. After all, Hughes had proposed a unit production cost $100,000 lower than Bell and had been awarded a development contract 57 percent higher than Bell's award. Further, while Bell would probably have been chosen for a

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[1] See George C. Daly, Howard P. Gates, and James A. Schuttinga, "The Effect of Price Competition on Weapon System Acquisition Costs," IDA Paper P-1435, Appendix E.

[2] See Aviation Week and Space Technology, August 18, 1975, page 43. The OH-6A had an empty weight of 1100 pounds, 1/8th the empty weight of the AH-64.

[3] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 3, March 10, 1982, page 357.

sole-source Phase 1[1], the Army considered the Hughes proposal to be good enough to justify a competitive Phase 1.[2] Furthermore, as Phase 1 progressed, Congressional testimony indicated that both contractors remained technically competitive.[3] Nevertheless, the suggestion that emerges from this and the previous section is that Hughes had reason to be hungrier than Bell while Bell had reason to be overconfident.

3. Importance of Cost among Program Objectives

In the original request for proposals (RFP) that initiated Phase 1, cost control was given considerable emphasis:

> Low cost is a principal objective of the program. The Government intends to develop an effective Advanced Attack Helicopter at the lowest possible operating and acquisition cost.[4]

For the initial source selection, the major evaluation factors would be the cost, technical and management areas. Cost and technical performance would be the most important areas and were to receive equal emphasis. The cost area included the following sub-areas listed in order of priority:

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[1] See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 166. Discussions at the PMO and at Hughes also suggest that Bell would have won a paper-only competition, since Bell's design approach and experience presented less apparent risk than the Hughes alternative.

[2] The Army had reserved the right to conduct a sole-source Phase 1 if one proposal had been clearly superior.

[3] See, for example, Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 9, 1976, page 4697.

[4] Based on US Army Aviation Systems Command, RFP DAAJ-01-73-R-0179, November 15, 1972.

- Operating and Investment Phase Cost,
- Development Phase Cost.

Investment cost would be evaluated, in part, against the design-to-cost (DTC) goal discussed above. In particular:

> If an offeror does not submit a design-to-production-cost proposal of $1.6 million or less, the proposal will be considered nonresponsive.[1]

At the end of Phase 1, a Letter of Instruction (LOI) was issued to supplement the original RFP in providing guidance for Phase 2 proposals. The LOI reiterated that the major evaluation areas for source selection would be technical, operational suitability, cost, management, and logistics. Cost and the combination of technical and operational suitability were to receive equal emphasis while management and logistics were considered to be of minor and equal importance. Further, the DTC objective was to receive the same management emphasis during Phase 2 as during Phase 1. Within the cost area, equal emphasis was to be given to:

- Investment Cost,
- Engineering Development Cost,
- Operational and Support Cost,
- TADS/PNVS Cost.

Thus, the RFP documents indicated that the Army would place considerable importance on expected procurement costs in

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[1]Based on US Army Aviation Systems Command, RFP DAAJ-01-73-R-0179, November 15, 1972, page 10.

evaluating proposals for Phase 2.[1] This emphasis on cost and on meeting specific DTC goals was relatively new to the Army at the time the AAH Program began.[2] But the contractors could recall that the Cheyenne Program had been cancelled, in part, because of high expected unit production costs. In addition, the actual selection of contractors for Phase 1 of the AAH Program appeared to verify the importance of production cost in the source selection process. For example, recurring unit flyaway costs for Hughes and Bell were estimated at the time to be approximately $1.4 and $1.5 million (respectively, in constant 1972 dollars, and including Government-furnished equipment).[3] Sikorsky lost the competition with a recurring flyaway cost well above $1.5 million even though Sikorsky's proposed Phase 1 R&D cost was $43 million, about the same as Bell's and $27 million below Hughes' proposal.[4] During Phase 1 both contractors established specific design-to-cost (DTC) groups to review all design changes for their impact on unit costs and to identify cost-saving changes themselves.[5]

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[1]Discussions at Hughes indicate that Hughes did expect unit costs to be an important factor in the source selection. As Hughes viewed it, the pressure for DTC control had originated at OSD but would nevertheless be taken seriously in the Army's source selection process.

[2]The Air Force was using DTC in its AX competition, and the Army was using it to some extent on its UTTAS program.

[3]Discussions at Hughes indicate that the importance of the DTC goal was reinforced after Hughes and Bell had been selected for Phase 1, when OSD delayed the program 30 days in order to challenge the proposed goals. Hughes had to prove that its DTC goal and technical approach were indeed feasible.

[4]See Aviation Week and Space Technology, July 2, 1973, page 17.

[5]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4982.

Further, both contractors described to the press their efforts to meet the Army's stringent DTC requirements.[1]

The DTC goal evidently did present a challenge. The goal of $1.4 to $1.6 million (in constant 1972 dollars) had been lowered from the Army's original intent due, in part, to pressure from OSD and from the rival AX attack aircraft development (whose cost goal was $1.4 million).[2]

4. Validation of Cost Estimates

The program management office (PMO) made a serious effort to estimate recurring unit flyaway costs during Phase 1 and to validate contractor claims. Since the DTC approach was relatively new, both the Army and the contractors had to develop methods as they proceeded. During Phase 1, the PMO conducted regular DTC reviews with the prime contractors to determine the possible award of incentive fees for DTC performance. These were detailed component reviews (down to the fifth level of the Work Breakdown Structure) at which the contractors attempted to sell their estimates as credible. The results formed the basis for the baseline cost estimate (BCE) used today and provided support to the Army in validating the realism of cost estimates in the contractors' Phase 2 proposals.

But would the Army be able to assess correctly the relative differences in expected unit costs for the two contractors? On the one hand, Phase 1 was intended as an

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[1]See Aviation Week and Space Technology, June 9, 1975, page 35, and August 18, 1975, page 42.

[2]See Defense Systems Management College, "Lessons Learned: Advanced Attack Helicopter," p. 5 and D-5. The Army originally considered a goal of $2.0 to $2.4 million.

engineering (rather than advanced) development stage that would largely complete development of the air vehicle. Prototypes were constructed in accordance with military specifications and some production engineering was included. Thus, the prototype configurations for the air vehicles would probably be close to the final configurations. But while the DTC estimates were based on the production methods to be used, detailed production planning was not done in Phase 1. The prototypes themselves included hog-out structures rather than production forgings. Further, the prototypes did not address the complexities of integrating the mission subsystems and, as discussed below, substantial changes were made as regards the planned subsystems during the last year of Phase 1. In addition, the Phase 2 proposals included some air vehicle design changes (to remedy problems identified during Phase 1) that the Army had approved but that had not been incorporated in the Phase 1 prototypes. As the program manager observed later:

> The design to cost reviews are those estimating pieces we were trying to do to leap forward and project what the production (cost) is going to be. But the first time that we really see a production estimate in its totality for all of the nuts and bolts and the industrial facilities, tooling, and all the things that have to go with it, is within the last year of the development, and as you get ready to go into that production proposal, the contractor now has a defined object and he either has to make it, and bet his company on doing it at a profit or sustain the loss.[1]

But while there are several reasons why the unit cost estimates in the Phase 2 proposals might have been wrong, the

[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authoriztion, Part 4, February 4, 1982, page 2017.

prototypes did give the PMO a reasonable basis for discriminating between the unit costs inherent in the competitive designs for the air vehicles. At the least, it would have been reasonable for the contractors to fear the PMO's ability to discriminate between the cost implications of the two designs.

5. Priced Production Options

The Phase 2 proposals did not include production options, priced or otherwise. The contractors did propose the design-to-cost (DTC) goals they would pursue during Phase 2, but their only incentive to achieve those goals would stem from the inclusion of an award fee provision (amounting to a maximum of 3 percent of target cost) in the Phase 2 development contract.[1]

6. Competition during Follow-On Procurement

The Army did not express plans during Phase 1 to introduce competition for production contracts after the winning AAH design had been selected. The RFPs for Phases 1 and 2 did express the Army's intent to break out and compete production contracts for subsystems and components where practical, but a competitive technical data package (TDP) for the entire system was not required. While the AH-1 Cobra Attack Helicopter was still in production, it was not a credible threat due to its performance limitations. A study was made late in Phase 2 regarding the use of the Sikorsky UH-60A Black Hawk for the AAH mission, but the UH-60A was

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[1] Since the Phase 1 prototypes did not include integration of mission subsystems, firm ceiling prices for production options would have presented too great a risk to the contractors.

rejected.[1] During Phase 1, the competitors had every reason to expect that the company selected for Phase 2 would be in a sole-source position for all ensuing production negotiations.

7. Correction of Deficiencies

Since the Phase 2 proposals did not include production options, the competitors were not required to commit to particular production terms and conditions. The eventual production contracts did not contain special provisions for the correction of design-related deficiencies for the air vehicle.

8. Summary

The structure of the AAH program provided the competitors with a real incentive to control the production costs inherent in their aircraft designs. Winning was important to the contractors because of the substantial size of the Phase 2 and future contracts as well as the importance of the continuing work to the winner's future standing in the helicopter industry. The Army made it clear that cost would be given as much emphasis as technical performance during the source selection and that its design-to-cost (DTC) ceiling for unit production cost must not be breached. Further, the construction of prototypes and the PMO's serious monitoring of DTC progress would give the PMO a reasonable chance to validate contractor cost estimates for the air vehicles. Thus, the contractors could not afford to ignore unit procurement cost. Nevertheless, the contractors were not required to propose priced production options so they would be

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[1] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, pages 475-6.

under no obligation to meet their cost estimates when production actually began. And there was no serious threat of procurement competition once the winning design was selected. While it was important during Phase 1 for the contractors to appear to control procurement costs, many of the actions necessary to make the estimates come true would not be taken until after Phase 1. Most importantly, mission subsystems would not be integrated until Phase 2. Also, because of the discrepancy in the experience and facilities of the two firms, Hughes had more reason to be hungry and Bell had some reason to feel overconfident.

D. RESULTS OF COMPETITIVE PHASE 1

1. Source Selection

On December 6, 1976, the Army selected Hughes as the winner and a Phase 2 development contract was awarded to Hughes on December 10, 1976. The decision was based on the evaluation of the competitive proposals, the DT/OT-1 flyoff and other supporting data. While the proposals reflected the Army's new mission equipment requirements (see discussion in Section 3 below), the evaluation was based on the same criteria utilized originally to select Hughes and Bell for Phase 1. According to the AAH Program Manager:

> The Hughes design was selected because it was adjudged to be the best value for the Government in terms of meeting performance objectives, operational suitability in a combat environment, lower costs, and the least risk system of achieving full-scale engineering development objectives in preparation for our production run.[1]

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4048.

The Army also observed:

> Hughes was selected on their overall superior performance, survivability, payload and endurance, and reliability, availability, maintainability (RAM) characteristics.[1]

It should be recalled at this point, however, that the Army placed relatively little importance (in their evaluation criteria) on management and logistics. As the Army testified later, Hughes:

> ...got the contract because of a clearly superior technical proposition in the face of expressed concerns by people... that Hughes was not the best to produce such a thing. I can't tell you exactly why the decision was made, but in fact I don't believe the Government in the past has placed enough emphasis on the capability of the manufacturer to perform.[2]

Hughes was not the low bidder[3] and its estimated unit recurring flyaway cost of $1.556 million (in constant 1972 dollars)[4] barely satisfied the DTC constraint of $1.6 million. Nevertheless, the unit cost estimates were not binding on the contractors and it is not clear which contractor had lower unit costs based on the Government's independent estimates.

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4116.

[2] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 3, March 10, 1982, page 357.

[3] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 2033.

[4] See C. David Weimer, "On Setting Avionic Subsystem Unit Production Cost Goals," IDA Paper P-1280, page 25.

The competing prototypes differed in a number of significant ways, giving the Army a good opportunity to test out alternative concepts.[1] Bell chose to use a teetering main rotor concept with two wide (42.6-inch) blades each constructed of two spars. Hughes utilized a fully articulated rotor concept with four shorter, narrower blades, each constructed of five spars. The Hughes approach proved to be quieter, more responsive, with less drag. Hughes also chose to design a much lighter aircraft, weighing 1,800 pounds less than the Bell aircraft. This also may have contributed to Hughes' superior performance. Hughes designed its own 30mm Chain Gun while Bell proposed to use General Electric's XM-188 Gatling-type gun. Hughes located its pilot behind and 19 inches above the gunner to give the gunner target visibility (and avoid a long relay tube for the gunner's direct-view optics) and the pilot a better feel for the aircraft (by being nearer its center of gravity). Bell, in contrast, located the pilot in front to provide better visibility for nap-of-the-earth flight, thinking that the gunner would rely mainly on his instrumentation. Also, in contrast to Bell, Hughes located the more expensive visionic equipment in front of the 30mm gun (underneath the aircraft) to afford the equipment better protection in the event of a crash.

During the DT/OT, the Bell prototypes failed to meet six out of seven major performance requirements, and were judged

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[1]For discussions of differences, see Aviation Week and Space Technology, June 9, 1975, pages 35-43; Aviation Week and Space Technology, August 18, 1975, pages 42-47; and G.K. Smith et al., "The Use of Prototypes in Weapon System Development," pages 163-167.

to have a total of nine deficiencies and 59 shortcomings.[1] The Hughes prototypes failed to meet three major performance requirements and had seven deficiencies and 64 shortcomings.[2] Both contractors' prototypes exceeded their (respective) original specifications for primary mission gross weight by more than 1000 pounds. But during the source selection process, the SSEB negotiated corrections with both contractors for all significant problems.[3] Thus, the Assistant Secretary of the Army was able to report:

> Either competitor's helicopter is by far the best machine of its kind in the free world, and the AAH Program has reinforced my long held belief in the tremendous benefits which accrue to the Army from competitive programs.[4]

2. Phase 1 Procurement Cost Savings

Even though unit procurement cost (UPC) for the AH-64 depended heavily on design and production activities that took place after Phase 1, it is still reasonable to ask what impact the competition had on the minimum UPC inherent in the design

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[1]Based on US Army Aviation Engineering Flight Activity, "Development Test I, Advanced Attack Helicopter Competitive Evaluation, Bell YAH-63 Helicopter, Final Report".

[2]Based on US Army Aviation Engineering Flight Activity, "Development Test I, Advanced Attack Helicopter Competitive Evaluation, Hughes YAH-64 Helicopter, Final Report."

[3]Thus Hughes reported that it had met all major performance requirements except that its maximum forward speed of 196 knots fell short of the 204 knot requirement. See Aviation Week and Space Technology, January 10, 1977, page 82. Bell's Phase 2 proposal included changes in crew positioning, gun location, and landing gear.

[4]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4033.

Hughes proposed fo Phase 2.[1] Probably the most important impact stemmed from the weight savings achieved by Hughes. At the beginning of Phase 1, Hughes proposed a primary mission gross weight of 13,200 pounds (compared to the Army's upper limit of 16,000 pounds), assuming a standard complement of eight TOW missiles, 800 30mm rounds, and sufficient fuel for a mission endurance of 1.9 hours. Bell proposed a mission gross weight of 15,000 pounds.[2] By the time of the competitive flyoff, the mission gross weight of the Hughes prototypes had grown to 14,242 pounds and of the Bell prototypes to 16,054 pounds.[3] Both contractors negotiated design changes with the SSEB to reduce the weights of their proposed production configurations, but the substantial weight difference between the competitive designs remained. Hughes, for example, obtained approval for design changes to reduce weight by over 600 pounds. Other changes increased the horsepower available to Hughes' main rotor system, so that (considering the 600-pound reduction) the proposed aircraft would have the same performance as the original 13,200-pound

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[1] Inherent costs are the minimum costs of producing a particular design assuming efficient methods are employed.

[2] See Aviation Week and Space Technology, June 9, 1975, page 38.

[3] See US Army Aviation Engineering Flight Activity, "Development Test I, Advanced Attack Helicopter Competitive Evaluation, Hughes YAH-64 Helicopter, Final Report," and U.S. Army Aviation Engineering Flight Activity, "Development Test I, Advanced Attack Helicopter Competitive Evaluation, Bell YAH-63 Helicopter, Final Report." In part, this weight growth reflected the usual tendency for prototypes to weigh more than production units for given designs.

aircraft.[1] Hughes agreed to a primary mission gross weight of 13,825 pounds in its Phase 2 contract, taking into account Army-directed changes in armament and mission equipment.[2] As of December 1982, the Army expected the mission gross weight of the AH-64 to be 14,694 pounds.[3] Thus, the final AAH will weigh 1300 pounds less than the Army's specified maximum and than Bell's DT/OT prototype.[4]

A direct relationship between aircraft weight and manufacturing cost, on average, has been widely observed and forms the basis for the cost-estimating relationships (CERs) used by the aircraft industry. In addition to direct material and labor savings, less weight may reduce the performance demands placed on subsystems such as propulsion and flight control. Of course, cost savings need not occur if the weight of a particular system is reduced through the use of exotic materials or expensive forming techniques, but this was not the case for Hughes. The AH-64 weight savings were achieved through the use of a test-to-failure design approach. That is, Hughes felt that the standard approach to determining required strength was too conservative and designed its airframe to only 90 percent of the usual specification.[5] Static tests on the fuselage (and additional tests on critical

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[1]See Aviation Week and Space Technology, January 10, 1977, page 82.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4825.

[3]Based on Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

[4]Since Bell's design was closer to the maximum, the Army probably would have placed more emphasis on weight control if Bell had won. For example, see the discussion of the T-700-GE-701 engine below.

[5]Hughes had followed a similar approach in designing the OH-6A.

areas) simulated flight loads to determine breaking points where additional strength was required. As a result, Hughes achieved a substantial weight savings and still designed sufficient strength to carry the unexpected Phase 2 weight growth. In contrast, Bell followed the conservative approach of adding strength (and weight) across the board and hence overdesigning its airframe in order to assure a reliable structure.[1] The Bell approach may have provided more potential for carrying future, Army-directed increases in mission weight requirements. But the Hughes approach reduced inherent unit production costs.

In addition to the airframe weight savings, Hughes pursued a lightweight approach for particular components. Hughes' rotor weight was reduced because it utilized shorter blades than Bell.[2] Further, Hughes developed its own 30mm Chain Gun in order to achieve a substantial savings in weight, parts count and unit cost compared to the GE XM-188 gun used by Bell.[3] While Hughes had invented the gun prior to the AAH competition, the gun had not yet been fabricated or fired. Hughes also redesigned the launchers for the TOW missiles in order to reduce weight and drag, although the TOW was eventually replaced and the launchers were not used.

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[1] See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 164.

[2] Discussions at Hughes indicate that Hughes' disc solidity was about the same as Bell's while the disc diameter was three feet less.

[3] The Hughes gun was expected to weigh only 104 pounds compared to 150 pounds for the GE gun. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4700.

The Phase 2 weight growth (from the specified 13,825 pounds to 14,694 pounds) was partially due to growth in the weight of subsystems Hughes could not control.[1] Weight growth also occurred as engineering changes were made and as original estimates proved to be too optimistic.[2]

The potential unit cost savings due to Hughes' lightweight approach were substantial, perhaps amounting to $100 to $165 thousand (in constant 1972 dollars) per unit.[3] The Hughes lightweight approach was not adopted only in order to reduce unit production costs. The approach reflected a company design philosophy and was directed, in part, toward achieving performance goals:

> The design goal of achieving maximum agility dictated use of a lightweight basic airframe, a rugged straightforward power train and a simple rotor system-- features that Hughes officials say also help the YAH-64 meet Army's strict design-to-cost requirements.[4]

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[1]Discussions at Hughes suggest a growth of 140 to 160 pounds due to unanticipated weight growth for the engines, the TADS/PNVS, and the Hellfire missiles.

[2]Discussions at Hughes suggest unanticipated weight growth of 150 pounds for aircraft wiring and 25 to 30 pounds for additional strengthening following fatigue testing. In turn, each increase in weight necessitated that more fuel be carried for a further weight increase.

[3]Hughes officials estimate a 15 to 20 percent difference in airframe weights between the Bell and Hughes designs (after subtracting the weight of the engines and some 4000 pounds for crew, armament and consumables from primary mission gross weights). A 15 to 20 percent savings in the cost of Hughes' $825 thousand (in constant 1972 dollars) airframe (as of the end of Phase 1) would amount to $124 to $165 thousand. A more conservative estimate of the savings would be the reported $100 thousand difference in the Hughes and Bell Phase 1 unit flyaway costs. See Aviation Week and Space Technology, July 2, 1973, page 17.

[4]See Aviation Week and Space Technology, August 18, 1975, page 42.

But whether the lightweight approach was motivated by performance or DTC objectives, it would not have been followed if competition had not been utilized during Phase 1.[1] As discussed above, if only one contractor had been used during Phase 1, it would probably have been Bell because Bell's design looked better on paper, its experience and facilities were solid, and its proposed R&D cost was substantially lower.[2] Thus, any unit cost savings associated with the lightweight Hughes design can be attributed to competition.

During Phase 1, both competitors claimed to be taking the Army's DTC requirement seriously.[3] For example, Hughes minimized the use of advanced materials in its airframe and made continuing efforts to simplify cost elements (e.g., the tail rotor bearing lubrication system.) Bell minimized the use of bonded panels and compound curvatures in its airframe structure and consolidated the avionics to reduce wiring requirements by 60 percent. The Army's estimate of recurring unit flyaway costs for the airframe increased only two percent during Phase 1 and the $1.6 million ceiling for the complete system still appeared achievable at the beginning of Phase 2. Nevertheless, neither competitor achieved its own DTC goal. The cost/performance trade-offs permitted under the DTC approach may have encouraged the contractors to develop less capable systems than they otherwise would have, in order to

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[1]Discussions at Hughes suggest that Hughes expected to gain both cost and performance advantages over Bell through its lightweight approach. Perhaps Hughes felt a bold approach was necessary in order to counter Bell's advantage as an exerienced, substantial firm.

[2]See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 166.

[3]See Aviation Week and Space Technology, June 9, 1975, pages 35-43 and August 18, 1975, pages 42-47.

stay within the DTC constraint. The four major performance goals were evidently quite difficult to meet within the Army's DTC constraint.[1] Currently, the Army estimates that performance will exceed the Army's minimum requirement for only one (i.e., vertical rate of climb) of these four goals.[2]

Competitively motivated procurement cost savings achieved through cost/performance trade-offs or producibility efforts during Phase 1 were built into the system designs and hence persist to a large extent in the production systems. But while the unit cost savings achieved during Phase 1 may have been real, subsequent procurement cost growth has been extraordinarily large. The following sections will attempt to sort out the sources of that growth and identify the net impact of the Phase 1 competition.

3. Requirements Changes for Mission Subsystems

The requirements changes with the greatest cost impacts occurred during the final year of Phase 1 (see Table A-2 for a chronology of key events). These changes were not reflected in the Phase 1 prototypes or the DT/OT-1 flyoff, but were incorporated into the contractor proposals for Phase 2. The prototype competition, thus, could not have had much impact on controlling any subsequent cost growth attributable to these requirements changes namely substitution of the Hellfire for the TOW Missile System, consequent upgrading of the fire control/visionics systems with the TADS/PNVS, and development of a NATO-standard 30mm ammunition round.

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[1]See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 162.

[2]Based on Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

Table A-2. CHRONOLOGY OF LATER AAH PROGRAM EVENTS

DATE	EVENT
March 1976	DSARC approves Hellfire and related changes.
October 1976	Hellfire engineering development contract awarded to Rockwell.
December 1976	DSARC II approves AAH Phase 2 development and contract awarded to Hughes.
March 1977	TADS/PNVS development contracts awarded to Martin Marietta and Northrop.
April 1980	TADS/PNVS maturity development contract awarded to Martin.
June-August 1981	AH-64 Operational Test 2 conducted.
March 1982	DSARC III approves AH-64 production.
April 1982	AH-64 production contracts awarded.
February 1984	First production aircraft delivery expected.
FY 1985	Initial operational capability expected.
FY 1990	Last production delivery expected.

The adoption of the Hellfire Missile System greatly enhanced the capabilities of the AAH. Most importantly, the Hellfire had an effective range exceeding seven kilometers[1] and thus permitted the AAH to operate at a safer stand-off range[2] than was possible using the enhanced TOW missile whose range was only 3.75 kilometers.[3] Survivability was also enhanced because the Hellfire had a shorter time of flight (for a given range) than the TOW so that the AAH would expose itself to enemy fire for a shorter period of time while directing the laser-guided missile to its target.[4] The Hellfire could be fired by an AAH (which then sought cover) and directed to its target by a scout helicopter or a ground designator, and in some cases the Hellfire could be fired from an AAH that never exposed itself to the target area. Further, the Army had eventual plans to incorporate a true fire-and-forget infrared seeker so that the Hellfire could guide itself to its target. In addition to its survivability advantages (for the AAH), the Hellfire was more accurate, maneuverable

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[1] See Aviation Week and Space Technology, May 30, 1977, page 14.

[2] The Soviet ZSU-23/4 air defense gun was said to have a maximum effective range of 4 km. See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 171.

[3] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1977 Appropriations, Part 3, page 126.

[4] The AAH might be exposed for as long as 15 seconds while directing the wire-guided TOW to its target. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 10929, Part 3, March 2, 1978, page 681.

and lethal, boasting a seven-inch warhead compared to the 4.9-inch TOW.[1]

With all of its advantages, why was the Hellfire not specified originally for the AAH? The Hellfire was too immature when the AAH Program, designed to minimize technical risk, was initiated. The Hellfire was always intended to be used on an AAH (Hellfire is an acronym for helicopter-launched, fire-and-forget missile system), replacing the TOW later in the helicopter's service life.[2] In May 1973, as the Army was preparing to award Phase 1 AAH contracts to Hughes and Bell, the Hellfire Program was still in a formative stage. Work had been done on laser seeker development and the guidance concept had been demonstrated, but the Army was still defining its seeker and missile airframe requirements. A competitive advanced development (AD) program (using Hughes Aircraft and Rockwell International) for the airframe was conducted between June 1974 and October 1975. Following a successful AD, the Hellfire was approved by the DSARC for full-scale engineering development (FSED) and use on the AAH in March 1976. A FSED contract for the Hellfire was awarded to Rockwell in October 1976.

Adding the Hellfire was expected to add approximately 400 pounds to the AAH's primary mission gross weight, largely because each Hellfire was expected to weigh 33 pounds more

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 10929, Part 3, March 2, 1978, page 682.

[2] See Aviation Week and Space Technology, October 23, 1972, page 16.

than the TOW it replaced.[1] In compensation, the Army decreased the quantity of 30mm rounds required for the primary mission from 800 to 500.[2] Using the Hellfire would pose different integration problems than the TOW and, as discussed below, would require different fire control and visionics. In addition, the Hellfire decision would have some impact on the air vehicle itself. Because the missiles were carried in launch pods hung from the AAH's stub wings, the added weight forced the wings to be strengthened. The wings and launcher pylons were also altered to correct a roll rate problem as the missile was launched.[3] And the Hellfire missile and launcher configurations increased drag, reducing the AAH's air speed. This may have contributed to the 1980 decision that the AH-64 use the T-700-GE-701 engine, a modification of the originally planned T-700-GE-700 engine that increased shaft horsepower from 1536 to 1690 and raised unit procurement costs by $8,000 (in constant 1972 dollars) per engine.[4] Integrating the Hellfire was originally expected to add $6,000 (in 1972 dollars) to unit recurring flyaway costs. The Hellfire missiles themselves were expected to cost $10,000 versus $4,000 for the TOW (in comparable dollars) but missile costs

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[1]Discussions at Hughes indicate that the Hellfire eventually weighed 98 pounds apiece as opposed to the expected 88 pounds. On the other hand, the Hellfire launchers were expected to weigh 150 pounds (compared to the 100-pound TOW launchers) but actually weighed only 138 pounds apiece. Thus, the complement of eight Hellfires and two launchers eventually weighed 54 pounds more than expected.

[2]See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 8.

[3]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 19, 1981, page 422.

[4]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, page 358.

were not funded within the AAH Program.[1] The Hellfire decision was expected to increase Phase 2 R&D costs by $67.3 million (in then-year dollars) and to add six months to the Phase 2 schedule.[2] Thereafter, the Hellfire development effort remained ahead of the AAH schedule and did not delay the AAH Program.

The decision to use the Hellfire forced changes in the AAH's fire control and visionics requirements. Because of the Hellfire's laser seeker, it was necessary to add a precision laser designator and automatic tracking capability. And a special television camera was required to provide visual clarity at the greater stand-off ranges possible with the Hellfire. The target acquisition/designation sight (TADS) included these items plus features that had been planned from the beginning of Phase 1 for development and integration during Phase 2, including direct-view optics, forward-looking infrared (FLIR) sensors (for night vision), indirect sensors, a laser range finder, and system stabilization.[3] A pilot night vision sensor (PNVS) with its own FLIR had similarly been planned from the beginning of Phase 1, but a new requirement was now established for a helmet-mounted display screen for data and visual images.

The TADS/PNVS systems were developed competitively. Originally, Phase 2 had been viewed as a low-risk program, but

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4720.

[2]See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 4.

[3]See Aviation Week and Space Technology, October 23, 1972, page 16 and Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4709.

the more demanding TADS/PNVS requirements had introduced significant risks as regards the TADS/PNVS cost and performance as well as the AAH schedule. Competition was introduced because:

> It is fairly high technology programs where we need to make sure that we use hardware to make decisions on rather than paper because paper proposals do not provide us a great deal of assurance that we are going to get what we are asking for at the cost and schedule that we think.[1]

The Army believed that the individual technologies required for the TADS/PNVS had already been developed.[2] The principal technical challenge would be to combine the components in a compact, lightweight package that could operate reliably in the high-vibration AAH environment.[3]

The competition was supported, in part, by funds originally intended to develop a similar visionics package for the (delayed) advanced scout helicopter (ASH). A sub-project was established within the AAH PMO to develop the TADS/PNVS and the RFP was released in September 1976. Phase 1 would include development and fabrication of nine prototype systems (each) by two contractors and would culminate in a three-month flyoff where the Army would test the competitive TADS/PNVS systems installed on AAH prototypes. On March 10, 1977, cost-plus-incentive-fee (CPIF) contracts were awarded to Martin

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1978 Appropriations, Part 3, March 16, 1977, page 542.

[2]The General Accounting Office raised some question at the time about the maturity of the laser designator candidates. See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 10.

[3]See G.K. Smith et al., "The Use of Prototypes in Weapon System Development," page 172.

Marietta and Northrop. The competition cost the Army approximately $48.5 million (in then-year dollars) for the Martin contract and $54.1 million for Northrop.[1] The competition was intense. The Northrop approach was viewed as technically superior and more conventional but also more expensive. The Martin approach was more controversial but also simpler and less costly.[2] The Martin design was particularly suitable for maintainability.

The flyoff was conducted between January and March 1980. The competitors were required to submit proposals for a follow-on, sole-source maturity phase to correct problems identified during Phase 1 and to complete development tasks (e.g., support items) that had been deferred until Phase 2 in order to avoid the higher cost of competition in Phase 1. The Phase 2 development contract would be CPIF, but the contractors were required to submit fixed-price-incentive (FPI) option proposals for the first two years of production of 98 units together with a clause to cap the recurring costs of the remaining 444 expected units.[3] The proposals were also required to include prices for a limited reliability assurance

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[1]Based on Selected Acquisition Report (U), December 1979. SECRET. Information derived for this report is Unclassified.

[2]Due to the perceived risk of the Martin approach, PMO officials believe Northrop would probably have won a paper competition.

[3]These production options were later renegotiated due to quantity changes. Also, for a description of the clause to cap recurring costs for the remaining units, see Defense Systems Management College, "Lessons Learned: Advanced Attack Helicopter," p. D-10. The contractors proposed target prices for recurring hardware costs for each of the production buys for years three through seven. Based on the difference between a proposed target price and the target price later negotiated for the corresponding year, a substantial incentive fee was to be added to or subtracted from the contract for the previous production year.

warranty (RAW) and a technical data package (TDP) for use in a potential follow-on production competition.[1] Because of the priced production options, the PMO placed less emphasis on validating DTC estimates than had been done during the AAH air vehicle competition.

Martin Marietta won the competition and was awarded the 26-month maturity phase development contract on April 9, 1980. Martin's TADS weighed approximately 500 pounds compared to 1200 pounds for a similar Air Force system. Further, the Martin system satisfied the PMO's design-to-cost (DTC) constraint of $333,000 for recurring unit flyaway cost in production.[2]

The TADS/PNVS experienced some development problems during Phase 2, including difficulties with the FLIR, the laser designator, and system reliability. As it turned out, Martin substantially underbid the cost of the CPIF maturity phase development contract.[3] In 1982, the program manager observed:

> The TADS work as advertised. We have had a few technical problems with it. We have fixes in hand. We are demonstrating those fixes work.[4]

The new TADS/PNVS requirements had relatively little

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, pages 415-417.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 5, March 18, 1982, page 881.

[3]For a discussion of buying in, see Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, page 415.

[4]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, part 5, March 18, 1982, page 880.

impact on the airframe structure. Through a successful weight control effort, the new requirements added only 25 to 50 pounds to the previously planned subsystem weight. Further, the externally mounted sensors had little or no impact on drag or aircraft performance.[1] The new TADS/PNVS requirements, however, did impact on aircraft unit costs by increasing the complexity of the subsystem integration task.[2] For example, by September 1981, the fire control subsystem's recurring flyaway cost was estimated at $164,000 (in 1972 dollars) as compared to a December 1976 goal of $43,000.[3] As noted above, the TADS/PNVS itself satisfied its DTC objective of $333,000 (in 1972 dollars) recurring unit flyaway costs. That goal was below the amount allocated for TADS/PNVS in the original AAH DTC goal of $1.6 million (in 1972 dollars) and the new requirements did not cause the Army to change the $1.6 million overall goal.

The TADS/PNVS changes did have a substantial impact on the AAH's Phase 2 development schedule. The schedule was extended by three months specifically for the TADS/PNVS changes[4] and then by another five months (to 50 months) based on both the TADS/PNVS changes and the maturity effort needed to correct aircraft problems identified during Phase 1.[5]

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[1]Based on discussions with PMO officials. The TADS/PNVS did contribute to the need to extend the forward avionics bays in Phase 2.

[2]Hughes adopted multiplexing in an attempt to reduce the number of wires required for the pilot's helmet and display system.

[3]Based on information provided by PMO officials.

[4]See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 9.

[5]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, page 4049.

Thus, the total schedule delay resulting from the decision to use the Hellfire on the AAH amounted to from nine to fourteen months. The TADS/PNVS effort continued to pace the AAH Program schedule, and there were some late TADS/PNVS hardware deliveries.[1] The TADS/PNVS changes were originally expected to increase R&D costs by $195.5 million (in then-year dollars).[2]

Another requirements change occurring in 1976 was the decision to develop a new 30mm round. In March 1976, OSD directed that the AAH utilize the same 30mm round employed by various NATO countries in their ADEN and DEFA guns, in order to promote NATO interoperability. It proved to be necessary to develop a new round for interoperability since the existing ADEN/DEFA rounds did not meet Army requirements.[3] The round was developed to Army specifications by Honeywell under subcontract to Hughes.[4] The new ammunition and associated gun and feed system modifications were expected to add 168 pounds to the AAH's primary mission gross weight (when carrying 800 rounds) compared with the original 30mm round. As a result, the Army reduced its primary mission requirement for ammunition from 500 to 320 rounds and for endurance (i.e.,

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 19, 1981, page 4230.

[2] See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 9.

[3] The derivative would have improved fusing and a dual-purpose anti-personnel and armor-piercing warhead in a lightweight aluminum case. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorization, Part 9, March 8, 1976, page 4704.

[4] See Aviation Week and Space Technology, April 16, 1979, page 51.

fuel) from 1.90 to 1.83 hours.[1] The ADEN/DEFA decision was originally expected to increase AAH R&D costs for Phase 2 by $2.1 million and increased schedule risk due to the separately funded $9 million ammunition development effort.[2]

Taken together, the Hellfire, TADS/PNVS, and ADEN/DEFA changes had a dramatic impact on Phase 2 R&D costs and substantially lengthened the development schedule. This delay increased actual production costs due to the impact of inflation in the later years. Originally, the changes were not expected to have much impact on unit production costs in constant 1972 dollars and they did not induce a change in the AAH DTC goal. The preceeding discussion indicates that the changes caused relatively minor modifications of the Phase 1 aircraft prototype designs and hence did not invalidate whatever may have been gained through the AAH competition. Nevertheless, the changes had an important impact on unit procurement costs by complicating the task of integrating subsystems into the production aircraft.

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 2, 1977, pages 4047-4048.

[2] See Comptroller General of the United States, "Status of Advanced Attack Helicopter Program," February 25, 1977, page 11.

4. Phase 2 Aircraft Design Changes

Phase 2 began in December 1976 as a planned 50-month effort to correct design problems identified during Phase 1 and to develop and integrate mission subsystems and support items that were not addressed during Phase 1. Hughes was to modify the Phase 1 prototypes and construct three additional prototypes to accommodate extensive Phase 2 test plans. During 1977, OSD and GAO questioned the AH-64's survivability, resulting in an FY78 budget cut and an extension of the Phase 2 program from 50 to 56 months.[1]

A number of airframe design changes were identified during Phase 1 for implementation during Phase 2. These included:[2]

- Change the engine exhaust cooling system (for reducing infrared signature) from an engine-driven fan to a passive, "black hole" exhaust duct system.[3] This change reduced weight by 60 pounds eliminated a 50-shaft-horsepower draw on the engine, simplified the tail rotor drive system, and had the same impact on performance as a 400-pound weight reduction.
- Reduce weight by 600 pounds through changes to the landing gear and the horizontal stabilizer (i.e., surface) on the tail.
- Change from square to swept tips on the main rotor blades in order to reduce vibration during high speed flight and achieve the forward air speed requirement.
- Raise the main rotor mast by six inches (in addition to a 9.5 inch raise during Phase 1) in order to

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 10929, Part 3, March 2, 1978, page 676.

[2] See Aviation Week and Space Technology, January 10, 1977, pages 82-83.

[3] Hughes had done some previous work on this concept for the Army and Navy.

reduce cockpit noise and vibration and improve air flow and aircraft lift.[1]

These changes were expected to have relatively little effect on unit production costs and did not cause the PMO to change its DTC objective. Other minor changes made during Phase 2 included:[2]

- Change cockpit window panels to reduce vibration and reflectivity.
- Extend forward avionics bays to increase capacity for avionics packages and gun equipment.[3]
- Streamline fairings on main rotor hub.
- Simplify intermediate and tail rotor gear boxes.
- Change cockpit configuration.
- Dampen seat vibrations.

The major airframe design change identified during the course of Phase 2 affected the AH-64 tail. The tail had been redesigned during Phase 1 to control adverse pitching moments. The horizontal stabilizer (i.e., surface) had been

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[1]Both contractors had initially tried to keep their rotors low in order to meet C-5A transportability requirements, but they encountered vibration and noise as well as clearance problems.

[2]See Aviation Week and Space Technology, November 21, 1977, pages 43-45; April 16, 1979, pages 49-51; and July 2, 1979, pages 17-18.

[3]The forward avionics bays (blisters on the forward sides of the fuselage) had been designed during Phase 1 in order to reduce the weight and cost of avionics wiring compared to the original, centrally located avionics bays. The forward bays were also more flexible, more accessible, and helped solve a center-of-gravity problem. This Phase 2 extension resulted, in part, from the Hellfire-related requirements changes.

raised to the top of the vertical stabilizer to form a T-tail.[1] As noted above, additional refinements were planned for Phase 2 in order to reduce weight. But during Phase 2 it was discovered that the new T-tail still generated adverse handling characteristics that restricted the AH-64 flight envelope as well as high dynamic loads and vibrations that would shorten aircraft life below the required 4500 flight hours. The solution adopted was to abandon the T-tail and design a low-mounted horizontal stabilizer that was movable and programable so that it would adjust automatically to the correct angle during flight. At the same time, the vertical tail structure was lengthened by two feet and the tail rotor was lengthened 10 inches and mounted 30 inches higher on the vertical stabilizer. The tail modifications were expected to cost $5 million to develop[2] and were partially responsible for an Army decision to delay production for one year from 1980 to 1981.[3] The modifications dramatically improved AH-64 performance. The eventual impact on production costs, however, is less clear. The programable stabilizer and its associated controls added weight, but that was partially

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[1]Discussions at Hughes suggest that problems had also been experienced with Sikorsky's fixed, low-mounted horizontal stabilizer for the UTTAS. Hughes had successfully used the T-tail concept on previous helicopters and adopted it for the AAH.

[2]See Aviation Week and Space Technology, July 2, 1979, page 18.

[3]The delay was also motivated by uneasiness over the planned concurrency of initial production and logistics development. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1981 Apropriations, Part 9, June 3, 1980, page 36.

compensated by changes that lightened the tail cone.[1] The Army observed in April 1980:

> Our current cost estimates have not reflected any large cost increase because of those things. ...I don't think we will get a very good fix on the cost impact of that tail design until we get closer to a production decision. It is a more complicated tail mechanism than the one it replaced. It is going to cost a little more. I don't think it is going to be that much more.[2]

A rough current estimate is that the tail modifications increased unit recurring flyaway costs by $17,000 (in 1972 dollars).[3] Hughes had originally avoided the programable horizontal stabilizer due to its added complexity and cost. Thus, the tail modifications provide an example of a design-to-cost (DTC) decision that did not prove valid.[4]

Another Phase 2 design change with high visibility was the decision to switch from the General Electric T-700-GE-700 engine with 1536 shaft horsepower (shp) to the T-700-GE-701 with 1690 shp. At the beginning of the AAH Program, the Army did not specify a particular engine but both Hughes and Bell chose to propose the T-700-GE-700. This engine was being developed for the Army's UTTAS Helicopter Program. The T-700-GE-700 was a major technical improvement over previous Army engines and commonality with the UTTAS engine promised to reduce AAH costs for both R&D and procurement. But continuing

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[1]Discussions at Hughes suggest the tail modifications may have increased weight by 50 to 60 pounds.

[2]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1981 Appropriations, Part 3, April 15, 1980, pages 651-652.

[3]Based on discussions at PMO.

[4]Based on discussions at Hughes.

growth in the weight of the AH-64 called into question the aircraft's ability to meet minimum performance requirements. The T-700-GE-700 would provide more than adequate power for the AH-64 at the contractual primary mission gross weight of 13,825 pounds. But by 1980, projected mission gross weight for production aircraft had grown to 14,200 pounds. While the Army expected to be able to meet its performance requirements at that weight with the T-700-GE-700 engine, there was some risk since the existing prototypes weighed more than 14,200 pounds.[1] In addition, the weight of Army aircraft typically grows over time in production, as new capabilities are added. Thus, even if the production AH-64s initially achieved the projected weight and satisfied the performance requirements using the T-700-GE-700, there would be little room for future growth. Finally, a February 1980 decision by the Secretary of Defense emphasized the importance of the AH-64 adhering to its performance requirements in order to remain adequate for conditions in the Middle East.[2] There was no problem in meeting performance requirements under assumed European conditions. Middle East conditions had previously been defined as 95½F at an altitude of 4000 feet. In February 1981, the Army formally approved use of the T-700-GE-701 engine for the AH-64.

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[1] In March 1981, the prototype was 700 pounds over the (then) projected production weight of 14,320 pounds and could achieve an air speed of 140 knots and a vertical rate of climb of 260 feet per minute, versus requirements of 145 knots and 450 fpm respectively. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 19, 1981, pages 417-418.

[2] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, page 382. In addition, there was concern over the ability to meet one-engine-out survivability requirements.

The T-700-GE-701 engine was chosen as a less costly alternative with less schedule risk than engaging in a strenuous program to reduce the weight and drag characteristics of the AH-64.[1] The T-700-GE-701 would be based on the T-700-GE-401 derivative that the Navy had already developed to increase power 10 percent (over the T-700-GE-700) for its Sikorsky SH-60B helicopter, so technical risk was low. While the T-700-GE-701 would operate at a higher temperature, it would be the same physical size as the T-700-GE-700.[2] The T-700-GE-701 would weigh four pounds more than the T-700-GE-700, would use somewhat more fuel and its unit recurring flyaway cost per engine would be $8,000 higher (in constant 1972 dollars).[3] This increase appears minor in comparison with the overall increase in recurring flyaway cost per engine (in 1972 dollars) from $93,000 to $205,000 between December 1976 and September 1981.[4] This latter increase was largely due to the increased cost of the original T-700-GE-700 engine, especially when changes in the UTTAS Program forced the AAH to take its engines at a higher point on GE's learning curve.[5] Since the Navy had already paid for the T-700-GE-401

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[1]Discussions at Hughes indicate that flight tests had already demonstrated that the airframe could carry the additional weight.

[2]See Aviation Week and Space Technology, September 7, 1981, page 28.

[3]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, pages 356-358.

[4]Based on information provided by PMO.

[5]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1981 Appropriations, Part 9, June 3, 1980, page 37. Also, information provided by the PMO indicates that as of May 1979, 56 percent of the reported T-700-GE-700 engine cost growth was attributed to the UTTAS changes.

development, the T-700-GE-701 was expected to cost the AH-64 PMO only $10.7 million in R&D.[1]

The addition of mission equipment due to changes during Phase 2 in Army requirements appears to have been relatively minor. Items added included radar warning devices and chaff dispensers.[2]

With the exception of the AH-64 tail modifications, the aircraft design changes identified after Phase 2 began appear to have been relatively minor, although their cumulative impact may have been significant. As noted above, primary mission gross weight did grow during Phase 2 from the contractual 13,825 pounds to a currently projected 14,694 pounds, partially eroding the presumed weight benefit of the Phase 1 competition. But the Phase 2 changes do not appear to have invalidated the Phase 1 air vehicle design.

5. 1981 Baseline Cost Estimate (BCE)

In preparation for a planned December 1981 production decision, the PMO developed a new baseline cost estimate (BCE) for the AH-64 Program during the spring and summer of 1981. When the BCE was formally presented to the Army in October 1981, it revealed a sharp increase in estimated procurement costs. Total procurement costs (in escalated dollars) increased from $4.821 billion in the official March 1981 estimate to $5.955 billion in the BCE, an increase of 23.5

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[1] Ibid., page 52.

[2] Ibid., page 37.

percent.[1] The Army could not fund the unexpectedly large increase without unacceptable disruption to other programs and so a major cut was eventually made in the planned AH-64 buy.

The BCE increase was particularly surprising to the PMO in light of its substantial efforts to know and control expected procurement costs. The PMO had conducted annual design-to-cost (DTC) reviews throughout Phase 2, including each of the 17 major subcontractors. At the individual parts level, the PMO reviewed drawings and expected man-hours and materials requirements. The PMO made a special effort to apply lessons learned from the cost problems being experienced by the Army's Black Hawk Helicopter Program. In addition, the Army had funded over $30 million for producibility engineering and planning (PEP) and had conducted three increasingly thorough production readiness reviews (PRRs) within four years. In 1980, the program manager felt confident in testifying:

> ... I can honestly tell you and sincerely state that this design estimate and the review of the production readiness of the factors that are going to build it, is the best that you have seen in any development program that the Army's run in the past 5 years.[2]

While the PMO fully expected the hardware costs in Hughes' production proposal (due in June 1981 but rescheduled) to be traceable to the previous DTC reviews, it learned (beginning with the May 1981 DTC review and continuing through

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1978.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 19, 1981, page 425.

the final PRR in August 1981), that the earlier estimates had been unrealistic.[1] As the Army reflected in early 1982:

> ... until May 1981 neither side had really faced up to the totality of the cost of this aircraft in a thorough enough way that the estimates could be traced back to real drawings, a real parts count, real tooling lists and so forth. In other words, they were living in a kind of dream world, if you will.[2]

What went wrong with the earlier estimates? In the first place, the PMO ultimately must depend on information provided by the contractor. With limited personnel, the PMO can only sample among the 330 work package elements during its DTC reviews. And in this case, the contractor had evidently been unaware of the growing costs. Hughes Helicopters had been in a process of reorganization since November 1979 and, in early 1981, Hughes announced sweeping changes in its top management. The new management included experienced executives from Boeing Vertol and Lockheed.[3] The new management revised almost all of the previous cost estimates, having discovered that the estimates did not take into account Hughes' own work experience.[4] Previously, the contractor (and the PMO) had had strong incentives to be optimistic in their estimates in order

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[1] As noted below, the 1981 BCE revealed substantial cost growth at Martin Marietta as well as at Hughes.

[2] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 3, March 10, 1982, page 325.

[3] See Aviation Week and Space Technology, April 6, 1981, page 60.

[4] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, part 4, February 4, 1982, page 2006.

to assure that the AH-64 would continue to be funded.[1] Further, the Phase 1 prototypes had not addressed the complexity of integrating the mission subsystems and the 1979 and 1980 cost estimates did not adequately reflect these costs as they were being determined in the development process.[2] That is, the cost increase was not due to last-minute design changes, but to a failure to recognize the costs of the design as it had evolved earlier. Of course, improvement in cost estimates is to be expected as a system prepares for the transition to production and finalized drawings become available.

6. Production Contract Negotiations

Developing a realistic BCE and negotiating a production contract proved to be separate matters. As noted above, the PMO's BCE for total procurement costs was $5.955 billion. The controller of the Army, however, determined that this figure was unrealistically low based on independent cost estimates and production uncertainty. Accordingly, when the ASARC III met in November 1981 to approve AH-64 production, the ASARC decided that prudence demanded that it include a reserve of some $563 million over and above the PMO's BCE in the AH-64

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, pages 1995-1996.

[2] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1998. As is discussed below, the competitive development of the TADS/PNVS during Phase 2 may have delayed Hughes' receipt of information needed to plan the integration of the TADS/PNVS into the air vehicle.

procurement program.[1] The PMO would be expected to negotiate within the BCE, but the reserve would be included in the program estimates to avoid further embarrassment before Congress or disruption of other Army programs. With the reserve, procurement costs would amount to $6.518 billion, which was more than the Army could afford. Accordingly, on November 18, 1981, the ASARC decided to reduce the AH-64 total buy from the previously planned 536 units to a new total of 446 units and to increase the maximum production rate from eight to twelve aircraft per month. These changes reduced total procurement costs to $5.864 billion including a reserve of $528 million. It was hoped that cost control would eventually permit the reserve to be used to procure additional aircraft.[2]

Hughes submitted its production proposal on December 31, 1981. The proposal covered 11 units in the FY82 buy plus long-leadtime items for the FY83 buy of 48 units. Extrapolating this proposal over the entire buy of 446 units resulted in a total procurement cost estimate of $6.36 billion.[3] By February 4, 1982 negotiations had reduced this estimate to $5.994 billion, still $658 million above the PMO's

[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1979.

[2] While the Army did decide (by December 1982) to increase the buy to 515 units, the first production negotiations assumed 446 units.

[3] Loc. Cit., Committee on Armed Services, page 1988.

BCE estimate for 446 units.[1] The Under Secretary of the Army was indignant at the Hughes proposal:

> We are either going to get it down or we will not do business with him. He is noncompetitive. We are not prepared to pay for his noncompetitiveness. ... He has to get his estimates down to something near ours or he is not going to have a contract.[2]

The PMO felt that the Hughes proposal was much greater than what the PMO thought it should be. The proposal for electrical work was thought to be two or three times as much as industry practice would indicate. Hughes had overstated labor rates for its new Mesa, Arizona location and included plant start-up reserves that the PMO considered unnecessary.[3] The cost of the main rotor was also an area of contention between Hughes and the PMO.

Early in Phase 2, the PMO's estimates of average manufacturing hours (in-house at Hughes) required per aircraft had exceeded those of Hughes. By the time the PMO completed its 1981 BCE, Hughes' estimate exceeded the PMO's by 16 percent. This discrepancy grew to 77 percent by the time Hughes submitted its December 1981 proposal.[4] For the first eleven aircraft, the greatest discrepancy in manufacturing hours was for electrical work, but substantial differences

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[1]It is not clear what relationship, if any, existed between the Hughes proposal and the Army's $528 million reserve. When the ASARC established the reserve in November 1981, it had already received some information regarding what Hughes' proposal would be. On the other hand, Hughes did not submit its formal proposal until December 31, 1981.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1998.

[3]Ibid., pages 1984-1987.

[4]Ibid., pages 1980-1983.

also existed for final assembly, production flight testing, and other manufacturing. Other PMO data indicated that the PMO's should-cost estimate for man-hours per pound of airframe closely approximated industry practice, while the comparable Hughes proposal was thought to be clearly out of line.

The high Hughes proposal, in part, may have reflected a conservative approach in light of the uncertainties of starting up production. As noted above, Hughes lacked production experience on medium-size helicopters and the company's survival depended importantly on profitable AH-64 production. In addition, Hughes may have taken into account the start-up difficulties experienced by the Army's Black Hawk Helicopter Program.[1]

As the negotiations progressed, the PMO's should-cost estimate increased somewhat as a result of fact-finding and Hughes' proposed cost came down substantially as a result of PMO efforts to convince Hughes that the PMO estimates were realistic and within industry practice. The two sides were in reasonable agreement over the hours that would be required to build the hypothetical 1000th unit but not over what it would take to build the first eleven (the PMO thought a multiplier of six to eight times as many hours per unit would be reasonable).[2] Agreement was finally reached at a level above the PMO's minimum should-cost estimate but within an acceptable range. DSARC III approved AH-64 production on March 26, 1982, and production contracts were awarded on April 15, 1982, four months after the intended contract date of

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 3, March 10, 1982, page 359.

[2]Ibid., page 337.

December 10, 1981. The FY82 contract for the air vehicle was FPI with a target price of $241.9 million, a ceiling of $282.8 million, and Government/contractor share ratios of 82.5/17.5 above target cost and 60/40 below.[1] The Army stated that the contrac did not subsidize Hughes or represent excessive costs and believed that the $528 million reserve described above would be available to purchase additional aircraft.[2]

Negotiations for the FY83 buy of 48 units were also difficult. The PMO intended to assure that the FY83 contract would be consistent with the learning curve implied by the FY82 contract but had relatively little information on actual production experience (the first delivery is not scheduled until February 1984). Thus, it was still difficult to convince Hughes that the PMO estimates were reasonable. The PMO had Hughes request bids from Bell Helicopters for some of the work in an attempt to validate its position.[3] The Army is considering a multi-year contract award for the FY84 negotiations.

7. Analysis of Phase 2 Cost Growth

Should the Phase 1 competition have been expected to prevent the cost growth that occurred during Phase 2? And does this cost growth invalidate the purported procurement cost benefits of Phase 1?

The procurement cost growth identified by the PMO's new BCE in October 1981 is summarized in Table A-3. The Hughes

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[1] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, page 458.

[2] Ibid., pages 471-475.

[3] Ibid., page 461.

Table A-3. PROCUREMENT COST GROWTH BY MAJOR CONTRACTOR (MILLIONS OF THEN-YEAR DOLLARS)

CONTRACTOR	MARCH 1981 SELECTED ACQUISITION REPORT ESTIMATE	OCTOBER 1981 BASELINE COST ESTIMATE	PERCENT CHANGE
Hughes	2730	3684	35
Martin Marietta	762	957	26
General Electric	920	922	-
Government	409	392	-4
TOTAL	4821	5955	24

[1]Based on Table 3 in Committee on Armed Services, U.S. Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1981.

change reflects increases in air vehicle hardware, system project management (SPM), tooling, training hardware, and nonrecurring testing costs. For Martin, the increases are in ground support equipment, hardware, SPM, and tooling costs. Thus, the overall procurement cost growth identified during 1981 included growth for items not addressed during Phase 1 such as support items and Martin's TADS/PNVS. Table A-4 indicates cost growth since the beginning of Phase 2 for average flyaway cost in constant 1972 dollars.[1] Prior to the 1981 BCE, approximately $70,000 (in 1972 dollars) in unit airframe cost growth had been identified,[2] so that the 1981 BCE revealed additional growth of $162,000 per airframe or 18 percent from what was already known. Cost growth for the engine, as discussed earlier, was partially due to changes in GE's production schedule due to changes in the Black Hawk Program (which developed the T-700-GE-700 engine) that forced the AH-64 to take its engines from a higher point on GE's production learning curve. Only $16,000 (per aircraft in 1972 dollars) has been attributed directly to the T-700-GE-701 modification, which in turn stemmed from changes from the Phase 1 design. Of the remaining subsystems, only the fire control subsystem showed substantial cost growth. Fire control growth reflects a significant increase in computer requirements to interconnect and control the mission subsystems, tasks that were not performed during Phase 1. The large increase in nonrecurring flyaway costs includes a $58,000 (in 1972 dollars) increase in the allowance for

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[1]These estimates exclude costs for support items (e.g., ground support equipment, training hardware and spares).

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 5, March 18, 1982, page 870.

Table A-4. AVERAGE FLYAWAY COST BY SUBSYSTEM* (MILLIONS OF CONSTANT 1972 DOLLARS)

	(1) DECEMBER 1976 DESIGN-TO-COST ESTIMATE	(2) OCTOBER 1981 BASELINE COST ESTIMATE	(3) PERCENT CHANGE (1) TO (2)
Airframe	.825	1.057	28
Engine	.186	.410	120
TADS/PNVS	.333	.323	-3
Fire Control Subsystem	.043	.164	281
Avionics	.066	.074	12
Hellfire Subsystem	.031	.026	-16
Gun Subsystem	.076	.079	4
Rocket Subsystem	.012	.002	-
Reserve	.028	-	--
Recurring Flyaway Cost	1.600	2.135	33
Non-Recurring Flyaway Cost**	.162	.397	145
Unit Flyaway Cost	1.762***	2.532	44

*Based on information provided by program management office.

**Includes tooling amortization, system program management (SPM) and an allowance for engineering change proposals (ECPs). For 1976, SPM and ECP estimates are based on December 1977 Selected Acquisition Report.

***The original DTC estimate included an additional $100,000 allowance for cost growth.

engineering change proposals and thus may be related to immaturity in the Phase 1 design. Thus, of the total increase in unit flyaway costs between December 1976 and October 1981, at most $306,000 (in 1972 dollars) or 40 percent of the increase is related to the airframe design that was the principal subject of the Phase 1 competition.[1]

The airframe cost itself was also subject to influences beyond the scope of the Phase 1 competition. As discussed earlier, the 1976 decision to use the Hellfire rather than the TOW missile (for which the Phase 1 prototypes had been designed) resulted in some Phase 2 design changes to the airframe. The Hellfire necessitated a strengthening of the AH-64's stub wings and, by increasing drag, contributed to the T-700-GE-701 decision. The Hellfire also forced development of a more sophisticated TADS/PNVS. The TADS/PNVS had relatively little impact on the airframe structure and its own recurring unit flyaway cost did not grow (in constant dollars), in part, because the TADS/PNVS development program was competitive.[2]

In addition to the aircraft structure, airframe costs reflect the task of integrating the mission subsystems, including the Hellfire, 30mm gun, 2.75-inch rockets, TADS/PNVS, navigation equipment, communications gear, and

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[1]Unit flyaway costs have increased from the 1981 BCE estimate of $2.532 million (in constant 1972 dollars) to a present estimate of $2.810 million, largely as a result of restructuring the program from 536 to 446 to 515 units to be procured. See Selected Acquisition Report (U), December 1972. SECRET. Information derived for this report is Unclassified.

[2]Nevertheless, as indicated on Table A-3, TADS/PNVS procurement costs other than recurring flyaway contributed substantially to the AH-64's overall cost growth.

threat-related devices. Installing and enabling these subsystems to operate was not addressed by the Phase 1 prototypes but had a major impact on Phase 2 airframe cost growth.[1] Both Hughes and the PMO underestimated the complexity and cost of the integration task.[2] For example, the number of separate electrical wires increased by a factor of four from estimates at the beginning of Phase 2, and the cost of electrical work played a major role in both the cost growth and the production contract negotiations.[3]

Available data do not permit the airframe cost growth to be decomposed between the portion attributable to subsystem integration and that due to other causes. As discussed earlier, there were a number of airframe design changes during Phase 2 due to problems with the Phase 1 design. The most important change was the complete redesign of the tail. The cumulative impact of the Phase 2 changes increased primary

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[1]While Hughes was the system integration contractor, the TADS/PNVS competition was managed by the PMO and the TADS/PNVS was Government-furnished equipment (GFE) to Hughes. Interface agreements were signed between Hughes and the two TADS/PNVS contractors to assure that Hughes would be able to make adequate provisions (e.g., weight, space, power, air conditioning, interface devices) for integrating the TADS/PNVS. The TADS/PNVS winner, however, was not selected until April 1980 so for the first three years of Phase 2 Hughes had to deal with both firms. Discussions at Hughes indicate that the flow of information on the TADS/PNVS designs was restricted within Hughes to protect the TADS/PNVS competition. Hughes had some difficulty planning the TADS/PNVS integration due to the design flexibility granted to the TADS/PNVS competitors and the continued design maturation after Martin was selected. Thus, the development of the TADS/PNVS relatively late in the program may have contributed to airframe cost growth.

[2]Based on discussions at PMO. Discussions at Hughes indicate that wiring weight increased from 300 to 550 pounds during Phase 2.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 1986.

mission gross weight from 13,825 to 14,694 pounds. While many of the Phase 2 changes were included in Hughes' proposal for Phase 2, a major purpose of the prototype competition was to avoid surprises such as the new tail and the weight gain. But while these surprises had an important impact on cost growth, their impact was not overwhelming.[1]

Another potential explanation for the Phase 2 cost growth is Hughes' unusual degree of dependence on subcontractors. During Phase 1, Hughes subcontracted 65 percent of its total effort whereas Bell subcontracted only 40 percent.[2] For the production phase, Hughes was expected to subcontract 61 percent of its work.[3] Under its "team" approach, Hughes acted much like a general contractor, coordinating the efforts of some 17 major subcontractors. Some of the subcontractors fabricated components to Hughes specifications, while a few participated in or held proprietary rights to their designs.[4] Notably, even the fuselage was subcontracted for fabrication.[5] While Hughes will do some fabrication work

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[1]The weight growth was only six percent and, as noted above, a rough estimate is that the tail modifications and the T-700-GE-701 engine decision increased unit costs by $31,000 (constant 1972 dollars).

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1975 Authorization, Part 9, March 29, 1974, page 4982.

[3]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 6, June 18, 1981, page 384.

[4]For example, Bendix retained proprietary rights to its drive shaft.

[5]The fuselage was fabricated by Teledyne-Ryan (TR). Discussions at Hughes indicate that TR was enthusiastic about winning the competition, and TR's experience proved very useful in enhancing Hughes' credibility. While Hughes had final responsibility for fuselage design, it consulted with TR for design-to-cost (DTC) engineering and other design support.

itself, it will assemble the AH-64 principally from components manufactured by other firms.

The team approach compensated for Hughes' lack of production experience. Rather than attempt to build up its in-house capabilities (which might not have been credible to the Phase 1 Source Selection Board), Hughes relied instead on other firms that already possessed the necessary expertise and facilities. But while the team approach made sense for Hughes, it did carry with it certain potential disadvant-antages. For example, greater reliance on subcontractors complicated the process of design iteration and increased Hughes' exposure to sole-source negotiations for components once the competition had been won, particularly for major components unique to the AH-64 Program.[1] Hughes was able to hold paper competitions for some components (e.g., the fuselage) in formulating its Phase 1 proposal but was limited by the short time horizon for submitting its own proposal.[2]

The greater cost growth, however, has occurred in the work that Hughes does itself. According to the Army:

> The major increases in recurring dollars are increases in the Hughes Helicopters in-house labor, primarily in the electrical and final assembly

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[1]At least one major subcontractor is reported to have taken advantage of its sole-source position in preparing its price proposal for Hughes, according to discussions at the PMO. Nevertheless, Hughes has been able to keep virtually all its major subcontractors under fixed-price contracts for the FY82 and FY83 production buys.

[2]Hughes had more leisure in Phase 2 to hold a paper competition for the horizontal attitude and reference system (HARS). There has been little dual-sourcing of component production, although a capacity shortage led to establishment of a second transmission source.

areas. ...There has been relatively small growth in major subcontractors.[1]

Further, the Army reported an increase of 30 percent in the estimated cost of the Hughes procurement contracts (over the life of the program), from \$2.656 billion (in escalated dollars) in March 1981, to \$3.440 billion in November 1981.[2] Within this increase, the cost of direct labor (provided by Hughes) increased by 50 percent, whereas the cost of materials (including the subcontractor-furnished components) increased by only 20 percent. Finally, the Army released a chart indicating that whereas the Hughes production price proposal initially exceeded the range of usual industry practice for man-hours per pound of airframe, the price of the fuselage subcontractor was thought to be well within the normal range.[3]

Thus, while the team approach may be difficult to implement successfully, it should be viewed principally as a symptom of Hughes' initial production limitations. The root problem was that Hughes had to build up its production (and to a lesser extent its design) capabilities from a very low level and relied on subcontractors to reduce the burden of the build-up. The Army took a production risk in selecting Hughes for Phase 2. The Under Secretary of the Army later observed that Hughes was selected:

> ... in the face of expressed concerns by people ... that Hughes was not the best to produce such a thing. I can't tell you exactly why the decision

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 11, 1982, page 475.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 2029.

[3]Ibid., page 1982.

> was made, but in fact I don't believe the Government in the past has placed enough emphasis on the capability of the manufacturer to perform.[1]

While the design-to-cost (DTC) reviews of Phase 1 considered production methods in order to estimate recurring flyaway costs, producibility engineering and planning (PEP) was performed largely in Phase 2.[2] Thus, a major determinant of production costs was not truly addressed during the competition. That is, the Phase 1 DTC reviews could estimate what it _should_ cost efficient producers to build the airframe designs, but they did not determine what it _would_ cost based on actual production plans.[3] And so, production was actually planned in a sole-source environment. There was no competitive pressure to force Hughes to control production costs. To some extent, the Phase 1 DTC estimates were wrong because they had to be optimistic and because forecasts of

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Part 3, March 10, 1982, page 357.

[2]Discussions at Hughes indicate that the Phase 1 DTC planning included a rough outline of how each part would be made, including the types of machines that would be used. Typically the most efficient machines available were assumed, but they did not always turn out to be affordable when investment decisions were made. Also, the engineers who brought the system into production were not the same production engineers who participated in the Phase 1 DTC effort.

[3]Symptomatic of this circumstance, Hughes did not announce until July 11, 1981, that it would build a new plant in Mesa, Arizona, to do the electrical work, final assembly, and flight testing. Hughes invested some $40 million of its own funds in the new plant, plus some $30 million for machine tools at Culver City, without guarantees from the Government (except possibly for some provisions in the initial production contract). The Mesa location was expected to reduce labor costs compared to Hughes' Culver City plant in the Los Angeles basin and was viewed by the Army as a medium-risk undertaking. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorization, Part 4, February 4, 1982, page 2020.

uncertain events are usually wrong.[1] But it may also be true that, with sufficient motivation, Hughes could have made those estimates come true.

To return to the questions that began this section, should the Phase 1 competition have been expected to prevent the Phase 2 increase in procurement costs? The answer is no. Much of the increase was due to items that the Phase 1 prototype design competition did not address, including the development and integration of the mission subsystems and of logistics and support items. In addition, serious producibility engineering and planning (PEP) and price negotiations are major determinants of cost growth and these efforts were conducted in the sole-source environment of Phase 2. Some portion of the Phase 2 growth, however, can be attributed to problems with the air vehicle design that was proposed at the end of Phase 1. A major objective of prototype competition is to prevent surprises such as the need to redesign the AH-64 tail and the Phase 2 weight increase.

Then, did the events of Phase 2 invalidate the purported procurement cost benefits of competition? The net answer is unclear. Certainly, the potential cost savings from Hughes' lightweight design were not eliminated. While the AH-64's primary mission gross weight increased during Phase 2 from the contractual objective of 13,825 pounds to a currently expected 14,694 pounds, the latter weight is still 1,300 pounds below the Army's stated maximum of 16,000 pounds and the Bell prototype weight at the flyoff of 16,042 pounds. But

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[1] For example, the five-spar main rotor blade had appeared to be producible in Phase 1 but proved to be unexpectedly difficult and expensive. The Army has funded an attempt to develop blades from composite materials in order to reduce costs and may compete the right to manufacture them if they are used.

potential savirgs are of little value unless the contractor can make them come true during production planning and execution, and can avoid offsetting cost growth in other areas. Overall, unit procurement cost (UPC) for the AAH increased from $2.36 million (in constant 1972 dollars) at the beginning of Phase 1 (i.e., December 1976) to $3.76 million in December 1982.[1] This increase of 59.3 percent was substantially greater than the 34.8 percent increase that would have been expected for the UPC of the median noncompetitive system discussed in Chapter III of the main report. But the growth in unit hardware costs for the airframe, the principal subject of the Phase 1 prototype competition, was somewhat lower. As indicated in Table A-4 above, airframe recurring hardware costs increased 28 percent (from December 1976 to October 1981). If the costs of integrating the mission subsystems could be excluded from airframe costs, this percentage would probably be lower. Thus, the Phase 1 competition probably did have an impact on the unit cost of producing the airframe itself, but any such savings are dwarfed by the overall UPC cost growth.[2]

E. CONCLUSION

The AAH prototype competition was structured so as to place considerable emphasis on control of the unit procurement costs inherent in the aircraft design. The PMO made a serious effort to assess the recurring flyaway costs of the competitive systems, and benefits such as the lightweight AH-

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[1]Based on Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

[2]The question naturally arises as to whether Bell, with its greater experience, would have been able to control UPC better than Hughes.

64 design would not have occurred without the competition. It is even possible that the Phase 1 airframe design could have been produced within the Army's design-to-cost (DTC) goal. Whether it could have will never be known since the competitive program did not include the steps necessary to control the costs of actually producing the winning design. That is, Phase 1 stopped short of substantial producibility engineering and planning (PEP) or low-rate initial production, and it did not leave the winning contractor with an incentive (such as firm-price production options) to control procurement costs during the design maturation and production transition phases. In addition, the development work deferred until Phase 2 (including mission subsystem integration and logistics items) was the subject of considerable procurement cost growth, making it difficult to isolate the cost growth for the airframe, which was the principal subject of the prototype competition.[1]

Thus, while procurement cost savings sufficient to offset the incremental costs of the competition are not apparent, this can be attributed to the way in which the competition and the overall development program were structured. A substantial portion of procurement costs were in fact determined in a sole-source environment.

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[1]Discussions at the PMO and at Hughes indicate doubt that potential procurement cost savings could have offset the considerable cost of carrying the AAH competition through full-scale development.

Appendix B

M-1 ABRAMS TANK SYSTEM

APPENDIX B

M-1 ABRAMS TANK SYSTEM

A. INTRODUCTION

Advanced development (AD) for the M-1 Abrams Tank System was conducted as a competitive prototype validation program. One of the two competitors was then selected to refine its design and prepare for production during a sole-source full-scale engineering development (FSED) phase. A requirement that the competitive proposals for the FSED phase include firm ceiling prices for the first two production options was not imposed until the end of the AD phase. Thus, the M-1 competition provides an opportunity to view competitive behavior before and after such a requirement is imposed. The M-1 competition is also rare in that the ceiling prices had to be proposed prior to the FSED phase and two and one-half years before the first production option was to be exercised. This can be viewed as an attempt to extend the benefits of competition through the FSED phase without continuing to pay two development contractors.

The M-1 discussion is organized as follows:

- Section B provides background information on the weapon system, its program history and its acquisition strategy;
- Section C discusses incentives to control procurement costs provided by the structure of the competition;

- Section D discusses the impact of the AD competition on system design and on procurement costs as they were later realized; and
- Section E presents concluding remarks.

B. BACKGROUND

1. Mission and System Description

The Army has described the tank as:

> ...the dominant offensive weapon on the mechanized battlefields....The tank's role in the combined arms team is to close with and destroy the enemy under all battle conditions, and in any level of conflict.[1]

The tank provides firepower and shock action to support advancing infantry and is expected to maneuver on the battlefield, to seize and hold terrain and to mix it up with the enemy in the 1000-2000 meter direct-fire range.[2] Accordingly, prime requirements for the tank include survivability, lethality, and mobility.

Survivability on the battlefield has become increasingly difficult with the proliferation of antitank guided missiles and with improvements in opposing tank gun ammunition.[3] Thus, tanks must operate in a combined-arms environment wherein antitank threats are suppressed by means of friendly artillery

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3226.

[2] See Armor, July 1981, page 66.

[3] Antitank missiles are improving and constitute a serious threat. Nevertheless, in the 1973 Arab-Israeli War 80 percent of the tanks destroyed were destroyed by other tanks. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 5, April 6, 1978, page 375.

and other supporting weapons. Survivability has been a prime consideration in the design of the M-1 Tank System. In the event that the tank is hit, survivability is greatly enhanced by the use of special armor material and techniques. The special armor is a dramatic innovation based on the British-developed Chobham technology and is said to provide the M-1 with twice the protection of previous tanks.[1] Further, M-1 ammunition and fuel storage has been compartmentalized away from the crew area, with special blow-out panels to vent explosions away from the tank. To make the M-1 harder for the enemy to detect/hit, its height is one foot lower than that of the M-60 and it carries two smoke generators. The M-1 also includes automatic fire detection and suppression systems, as well as equipment to distribute uncontaminated air to individual masks in the event of chemical or biological threats.

The main tank gun is the M-68 rifled 105mm gun, but a German-designed, smooth-bore 120mm gun will be used beginning with 1985 production. The M-1 can carry fifty-five 105mm rounds (and will carry forty 120mm rounds).[2] Other armament include a 0.50 caliber machine gun at the commander's station as well as two Belgian-designed MAG-58 7.62mm machine guns, one mounted coaxially with the main gun and one at the loader's station. The fire control system permits remarkable accuracy for the

[1] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 388.

[2] See International Defense Review, December 1981, page 1662.

main gun.[1] The gunner's primary sight incorporates two-power daylight optics, a passive thermal-imaging system for night vision, and a neodymium YAG laser range finder. A digital computer automatically receives information on ambient wind, static vehicle cant, and target lead angle and range (as well as other information obtained manually) and calculates full ballistic solutions for the target at which the gunner aims. Electrohydraulic controls automatically position the gun. Images and data are displayed to the gunner via a monocular eyepiece. Through an optical relay, the commander may also view the gunner's primary sight. In addition, there is an auxiliary optical sight.

Both survivability and lethality are aided by the M-1's strong shoot-on-the-move capability. The M-1 provides a stable firing platform while moving across rough terrain at speeds up to 30 mph.[2] The fire-on-the-move capability is provided by an advanced torsion bar suspension system and by stabilization of the turret and the gunner's primary sight.

The M-1 is powered by a 1500-horsepower turbine engine. With a horsepower-per-ton ratio of 25, the M-1 can achieve exceptional speed and acceleration.[3] The powerful engine, together with an advanced automatic transmission, greatly

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[1] In operational tests, the M-1 has proven twice as capable of scoring first-round hits as the M-60. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1982 Appropriations, Part 3, May 19, 1981, page 428.

[2] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3175.

[3] The M-60A1 has a horsepower-to-weight ratio of only 15. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 391.

enhances the M-1's agility and survivability on the battlefield.

2. Early Program History

Development of the M-60 Tank (based on the M-48 Tank) was initiated in 1955. The first M-60 was fielded in 1960, and with continuing product improvements the M-60A3 continued in production until the 1980s and will remain a major element of the US tank inventory for years to come. The longevity of the M-60 is also due to the cancellation of the original program to develop a replacement for the M-60, namely the MBT-70. The MBT-70 Tank System was jointly developed by the US and the Federal Republic of Germany (FRG) in a program approved in August 1963. An engineering development contract was awarded to General Motors in December 1965, and required the construction of six prototype vehicles.

The MBT-70 represented a major advance over previous tanks. It was powered by a 1475-horsepower diesel engine[1] giving it excellent mobility. For main armament it carried a long-tube, 152mm gun capable of firing both conventional rounds and the Shillelagh missile.[2] The MBT-70's fire control system was very sophisticated and advanced suspension and stabilization systems gave the tank a significant cross-country fire-on-the-move capability.

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[1] The M-60 is powered by a 750-horsepower diesel. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1972 Appropriations, Part 6, June 1, 1971, page 517.

[2] The missile provided greater accuracy at long range while conventional rounds were more effective against multiple short-range targets due to quicker loading and shorter flight time. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1973 Appropriations, Part 1, January 25, 1972, page 454.

By January 1970, however, the US and the FRG agreed to pursue unilateral tank development programs while seeking to continue cooperation and exchange information. The joint effort was terminated due to the difficulties of managing a multinational effort and particularly to differences between the US and the FRG regarding tank design objectives. As the XM-1 project manager observed later:

> I think the Europeans, looking at their environment, and what they assess as the unique requirements of the European theater, look at the tank as a defensive weapon. For this reason there is a much greater concern with long-range firepower. We believe that you can supplement the tank and its firepower in the long-range role much more effectively with missiles, and air-delivered weapons. If you optimize for the long-range defensive, you compromise the tank's basic capabilities in the offensive role, which we think is predominant.[1]

In addition, the estimated unit cost of the MBT-70 was extremely high, particularly due to the degree of sophistication in the fire control system.

The follow-on US version of the MBT-70 was dubbed the XM-803. The XM-803 adopted a US-designed diesel engine with 1250 horsepower and a US-designed transmission.[2] While the XM-803 utilized many of the MBT-70 subsystems, a strenuous effort was made to scrub requirements and reduce complexity and estimated manufacturing costs. Nevertheless, as the XM-1 project manager later observed:

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7011.

[2]The MBT-70 was to use a German-designed engine and transmission. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1972 Appropriations, Part 6, June 1, 1971, page 519.

> ...Congress perceived that the XM-803 was also unnecessarily complex, excessively sophisticated, and too expensive. This coupled with user disenchantment with the tank's main armament, automatic loader, and other features precipitated Congressional intervention in the program. In November 1971, through the House Appropriations Committee report, Congressional direction was to terminate the XM-803 program.[1]

Inadequate armor in light of the developing antitank guided-missile threat also had been cited as a reason for cancelling the XM-803.[2]

At the same time that Congress directed termination of the XM-803, it recognized the need for a new tank and provided funds to initiate a new program. An Army task force thoroughly reevaluated tank philosophy and requirements between February and August 1972. Requirements for a new tank were further scrubbed before the materiel need statement was approved by the Army on November 9, 1972 and before the program was approved by OSD on January 18, 1973. The procurement objective for the new XM-1 Tank was set at 3312. In June 1973, contracts were awarded to General Motors (GM) and Chrysler for a competitive prototype validation phase.[3] A summary of these early program events is provided on Table B-1.

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[1] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 85.

[2] See Armor, July 1981, page 65.

[3] Ford had also considered bidding but eventually dropped out without submitting a proposal. Ford had not built a tank since the era of the Korean War.

Table B-1. CHRONOLOGY OF EARLY PROGRAM EVENTS

DATE	EVENT
August 1963	Joint MBT-70 development program approved.
December 1965	Engineering development contract awarded to General Motors.
January 1970	US initiates XM-803 unilateral follow-on to MBT-70.
December 1971	XM-803 development terminated.
November 1972	ASARC 1 approves XM-1 development program.
January 1973	DSARC 1 approves XM-1 development program.
June 1973	Phase 1 validation contracts awarded to GM and Chrysler.
February to April 1976	Competitive prototype testing at DT/OT-1.
July 1976	Initial source selection.
November 1976	Final source selection and contract awarded to Chrysler for Phase 2 FSED/PEP.

3. Acquisition Strategy

The development objectives for the XM-1 tank, taken together, were particularly demanding. Congressional pressure forced the Army to adhere to an accelerated development schedule in order to field a tank (i.e., attain initial operational capability (IOC)) within seven years of beginning development. The Army would have preferred an eight-to-ten year development program in order to avoid excessive concurrency and permit adequate testing so that the initial production systems would be mature and reliable. Congress, however, was unwilling to accept a 20-year delay from the initial fielding of the M-60 to the introduction of the XM-1, and some members thought a tank could be developed in as few as three years.[1] The seven-year program finally agreed upon would in fact require considerable concurrency.[2]

At the same time, Congress mandated that the complexity, sophistication, and unit cost of the new tank be tightly controlled. In its 1972 tank requirements studies, the Army initially considered a (lower boundary) cost goal of $400,000 (in constant 1972 dollars) for recurring unit hardware costs. But the unit hardware cost goal had increased to $507,790 (in 1972 dollars) by the time the program was approved. The increase was largely due to an increase of ten tons in the prospective size of the tank in order to

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[1]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 85, 103, 104.

[2]The IOC was achieved in January 1981, only seven months later than planned, including a four-month source selection delay imposed by the Secretary of Defense.

accommodate more armor.[1] The $507,790 goal was developed based on four parametric studies by the Army and other information, and was initially viewed as a mid-point in a band of acceptable costs. In the approved program, however, the $507,790 figure became the design-to-unit-hardware-cost (DTUHC) ceiling. Comparable costs for the M-60A1 and the XM-803 tanks were $339,000[2] and $611,000[3] respectively.

But while the short development schedule and tight DTUHC ceiling mandated that the XM-1 Program avoid substantial technical risks, both the Soviet threat and the need to justify a new development program required that the XM-1 clearly out-perform existing tanks. Thus, the XM-1 was required to achieve a significant (i.e., more than marginal) improvement over the M-60 series of tanks in the areas of survivability, firepower, mobility, and RAM-D (i.e., reliabilty, availability, maintainability, and durability). For example, Table B-2 compares certain XM-1 performance requirements with the capabilities of the M-60A1 and M-60A3 tanks. The Army also was interested in developing a tank with more growth potential than remained for the M-60 series. In achieving a superior tank the Army was free to utilize, repackage, or refine components from the XM-803 Program, but Congress made it clear it expected more than a warmed-over

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 387.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3217.

[3]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 5, April 6, 1978, page 313.

Table B-2. COMPARISON OF XM-1 REQUIREMENTS WITH M-60 SERIES TANKS

CHARACTERISTIC	XM-1	M-60A-1	M-60A-3
Acceleration to 20 mph	6-9 seconds	15 seconds	n.a.
Road Speed	40-50 mph	30 mph	30 mph
Cross-Country Speed	25-30 mph	10-12 mph	n.a.
Speed on 10 Percent Slope	20-25 mph	11 mph	n.a.
Combat Loaded Weight	49-58 tons	54.8 tons	57.3 tons
Width	120-144 inches	142.8 inches	142.8 inches
Height to Top of Turret Roof	90-95 inches	106.5 inches	106.5 inches
Main Gun	105mm	105mm	105mm
Number of Main Gun Rounds Carried	40-50	63	63
Unit Hardware Costs[1]	$507,790	$339,000	$432,000
System Reliability (mean miles between failure)	320-440	159	n.a.
System Maintainability (mean maintenance/ operational hours)	0.66-1.25	n.a.	n.a.
System Availability	89-92 percent	82 percent	n.a.
System Durability (power train)	4000-6000 miles	6000	n.a.

Source: Materiel Need Document requirements for XM-1 and other data taken from Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1975 Appropriations, Part 4, April 29, 1974, page 1186; Committee on Armed Services, U.S. Senate, Hearings of Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3217, 3221; and International Defense Review, March 1976, page 481, 484.

[1]Constant FY 72 dollars, and adjusted to XM-1 production rates.

version of the XM-803.[1] Thus, the XM-1 development would have to tread a fine line, achieving superior performance by taking advantage of emerging technologies and new components but avoiding great technical risks that would jeopardize the schedule or DTUHC goals.

The XM-1 requirements also reflected an Army decision to optimize for the tank's offensive role. This change from the defensive MBT-70 philosophy required greater armor protection and elimination of the Shillelagh missile. Since the TOW and Dragon antitank missiles would now be available for the longer-range (i.e., 2000-3000 meter) defensive role, the tank could revert to the 105mm cannon with its improved ammunition for the quick-reaction, short-range, multi-target role.[2] The adoption of an offensive philosophy was also aided by the emergence of the new special armor to enhance battlefield survivability and by the elimination of the joint program with the defensive-minded Germans. Other changes from the XM-803 included elimination of the automatic loader and reversion to the four-man (rather than three-man) crew as well as a general attempt to scrub requirements down to a minimum austere level.[3]

In order to achieve its development objectives and at the specific urging of Congress, the Army adopted an acquisition strategy that included a competitive advanced development

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1973 Appropriations, Part 1, January 25, 1972, page 457.

[2]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 388.

[3]For examples of requirements eliminated, see Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3198.

(AD)/prototype validation phase. Two contractors would be asked to design and test tank systems that satisfied the requirements of the Materiel Need Document without exceeding the DTUHC ceiling of $507,790. The contractors would be given considerable flexibility with regard to both the capabilities of their systems and the methods of achieving those capabilities. Thus, the Materiel Need Document defined many requirements in terms of performance bands that indicated a range of desirable performance, bounded at one end to assure adequate performance and at the other end to prevent over-sophistication. As the Army observed:

> We would like to have the maximum performance, but we are sticking to a design-to-unit cost and we therefore have to give the contractor the ability to make trade-offs to meet the design-to-cost goal.[1]

The contractors would be free to change their designs and trade off (i.e., reduce or eliminate) capabilities at their own discretion in order to meet the DTUHC goal, provided that they did not violate the performance bands. They were also free to propose necessary changes that violated the bands subject to Army approval. As additional guidance, the contractors were provided with a prioritization of 19 design characteristics to be observed when making their trade-offs. As indicated on Table B-3, survivability was given top priority. Overall, the Army was prepared--

> ...to sacrifice performance in narrow areas to stay within the cost ceiling, except that we were not willing to accept a tank, overall, that was not a significant improvement over the M-60A3, or one with reliability, availability, maintainability or

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1975 Appropriations, Part 4, April 29, 1974, page 1186.

Table B-3. PRIORITY OF TECHNICAL CHARACTERISTICS (LISTED IN DESCENDING ORDER OF PRIORITY)

1. Crew Survivability (all aspects)
2. Surveillance and Target Acquisition Performance
3. First and Subsequent Round Hit Probability
4. Time to Acquire/Hit
5. Cross-Country Mobility
6. Complementary Armament Integration
7. Equipment Survivability
8. Environmental
9. Silhouette (except width)
10. Acceleration/Deceleration
11. Ammunition Storage
12. Human Factors
13. Producibility
14. Range
15. Speed
16. Diagnostic Aids
17. Growth Potential
18. Support Equipment
19. Transportability

Source: Request for Proposal DAAE07-76-R-0491, March 4, 1976.

durability performance below the minimum essential requirements.[1]

Competition during the prototype validation phase would assure that the contractors would cooperate with the Army's cost and schedule goals and still design a tank with superior performance. As the Army testified:

> That competitive aspect we believe very sincerely will reduce the costs of the tank without any sacrifice in effectiveness.[2]

Another important aspect of the XM-1 development strategy was that the Army would attempt to minimize the number of requirements changes it imposed during the development program. It was provided the funding and the time (most of 1972) to study its user requirements thoroughly and embody them in a solid Materiel Need Document. Thus, contractor design freedom would be enhanced and costly incremental requirements growth could be avoided. At the same time, users would remain involved in the program:

> The armor center team, a formal user group, will monitor system progress and consult with the PM to provide input for design decisions, especially those affecting operational utility and maintainability.[3]

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[1]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 87.

[2]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 386.

[3]Ibid., page 396.

Finally, the Army considered the XM-1 to have as high a priority as any of its development programs so that funding adequate to meet the program schedule could be expected.[1]

The initial competitive phase was planned (and accomplished) as a 34-month effort. Each contractor would be awarded a CPIF contract to design, fabricate, and test one complete prototype system plus an automotive test rig and a ballistic hull and turret. The contractors would be responsible for complete systems, including the integration of Government-furnished equipment (GFE) such as the armament and communications equipment. The night vision system (to be based on a system being developed for the M-60) would be the only major contractor-furnished equipment item not integrated during the competitive phase. The competitive phase was intended to be an advanced development (AD) program to demonstrate the potential of each contractor and design to meet the XM-1's operational and cost requirements during the follow-on full-scale engineering development (FSED) phase.[2] Phase 1 was to end with a competitive evaluation of the competing designs based on the results of developmental and operational testing (DT/OT-1) scheduled for February through April 1976, as well as on contractor proposals for the FSED phase. To avoid delays in the construction of 11 additional prototypes by the winning contractor during the sole-source

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3168.

[2] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 89.

FSED phase, both contractors were awarded funds for the advance procurement of long-leadtime items (LLTI).[1]

The sole-source follow-on phase was to be a 31-month (later changed to 36-month) FSED, overlapping by six months with a low-rate-initial-production (LRIP) effort. The LRIP would be initiated after DT/OT-2 validated the FSED designs, and additional tests (i.e., DT/OT-3) would be conducted with LRIP vehicles before full-scale production would be approved. The LRIP was thus a device to speed fielding of the XM-1 by initiating production at a relatively low rate while the design was still relatively immature.[2] It could be expected that design problems would continue to surface during LRIP and some engineering fixes would have to be retrofitted to LRIP systems.[3] The early LRIP effort forced production facilitization to begin within the first six months of the FSED phase and LLTI for production also had to be ordered relatively early.[4]

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[1]Eight million dollars per contractor was requested for LLTI as well as to support their engineering staffs during the transition to FSED. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 6990.

[2]The immaturity would be due to inadequate early testing and could be expected to have more impact on durability and support costs than on mission-related performance. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 745.

[3]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 1, February 7, 1978, page 168.

[4]These early preparations for production would have made a continuation of competition into the FSED phase particularly expensive.

4. Conduct of Competitive Phase

The execution of the competitive AD phase was evidently quite successful. As the project manager (PM) observed to Congress near the end of the competitive testing:

> Thus far, we are on track. The hardware looks good. We are on the schedule you authorized--the program has not changed. In the area of cost, we continue to maintain activity within the funds initially projected.[1]

There were, of course, development problems[2] but the prototype systems were delivered for testing on schedule. As noted above, the contractors were given a great deal of design flexibility and retained configuration control. PMO engineers, who would normally be closely involved in the design effort, had to refrain from offering advice even when it was solicited by the contractors. Nevertheless, the Army did educate the contractors regarding armor and compartmentalization techniques that the Army had developed.

The CPIF contract costs amounted to $87.969 million for GM and $68,999 million for Chrysler. The PM explained the difference as follows:

> As far as the work scope is concerned, the requirements based on the two contractors were identical. It is simply the manner in which they internally manage, and the way in which they make the decision on make versus buy alternatives, etc.[3]

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 6986.

[2]For example, GM unexpectedly had to redesign its turret for four months. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1975 Appropriations, Part 4, April 29, 1974, page 1189.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3178.

Since the contract awards were negotiated based on the contractor cost proposals at the beginning of the AD phase, the disparity in costs may also reflect differences in bidding strategies.[1]

The complete system prototypes were delivered to the Army for a combined developmental/operational test (i.e., DT/OT-1) at Aberdeen Proving Ground, Maryland from January 31, 1976 through May 7, 1976. Armament, fire control and mobility tests were included to determine the performance potentials of the competing designs. An M-60A1 tank also was tested as the baseline system. The OT portion of the test included two weeks of simulated combat operation utilizing crews of troops from Ft. Knox and Ft. Hood. In addition to the full system tests, competing automotive test rigs were operated for more than 3000 miles. Hull and turret ballistics tests were initiated earlier (October 1975). The results of the DT/OT-1 tests were evaluated by the Source Selection Evaluation Board (SSEB) to validate contractor proposals for the FSED phase in preparation for a July 1976 source selection decision.

5. Changes in Requirements

The XM-1 requirements for the FSED phase differed somewhat from those at the beginning of the AD phase. Following the Arab-Israeli War of 1973, the Army established a special study group to reexamine thoroughly the Materiel Need Document in light of the Mideast experience, with a report due in June 1975. One change that resulted was that the Bushmaster 20-30mm cannon was replaced as the coaxial (i.e., mounted parallel to the main tank gun) weapon by a 7.62mm

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[1] That is, Ford had also been expected to submit a bid.

machine gun. The original concept had been to utilize the cannon against lightly armored targets and thus reduce the number of more expensive main gun rounds required (from 63 for the M-60 to 40-50 for the XM-1). However, the reevaluation determined that tank crews would use the main gun against lightly armored vehicles anyway and that a machine gun was needed to provide suppressive fire against antitank weapons.[1] The change permitted an increase in main gun rounds carried to 55. Design changes would be required to accommodate the additional ammunition storage as well as to improve armor and compartmentalization, reduce hydraulic fluid flammability, eliminate the searchlight, etc. These changes were incorporated in the requirements for the FSED phase and only partially implemented during the competitive AD.

Other requirements and program changes resulted from continuing efforts to standardize tank materiel within NATO. Following the termination of the joint MBT-70 development effort discussed above, the Federal Republic of Germany (FRG) utilized portions of the MBT-70 technology to develop its own Leopard II (L2) Tank System. Eventually, the FRG proposed to develop a version of the L2 modified to meet US requirements, namely the L2AV. In a December 1974 Memorandum of Understanding (MOU), the US and the FRG agreed that the US would conduct a comparative test and evaluation of the L2AV at Aberdeen Proving Ground between September and December 1976, employing the same tests and criteria as would be used in the

[1]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 210, 211.

earlier evaluation of the GM and Chrysler prototypes.[1] The US and Germany also jointly funded a study by FMC (with reports due in July and December 1976) to ascertain the cost and schedule impacts of producing the L2AV under license in the US.[2]

The US agreed to evaluate the L2AV both as a tank system and for potentially superior components in the interests of NATO standardization, and to provide additional competition.[3] The evaluation was initiated by OSD and unfolded in a political atmosphere.[4] The Army user group had examined and rejected the L2 in 1972, and the Army had tested the L2 chassis in 1974. The XM-1 PM had concluded:

> But overall, I think the XM-1 is a very substantial margin over the Leopard II in its current form, and I think it will continue to be superior even after the Germans make the modifications....[5]

Further, both GM and Chrysler are reported to have examined the L2 and concluded that it would not be a viable competitive threat because it was less effective and far more costly than

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[1]The L2AV could not be ready in time for the scheduled DT/OT-1 and the Army did not wish to delay its planned July 1976 source selection between GM and Chrysler.

[2]The US planned to compete the right to build the L2AV in the US in the event it were selected.

[3]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 88.

[4]For example, West German Defense Ministry officials warned that the FRG could not afford its planned AWACS purchase in the US unless the US procured the L2AV. See <u>Aviation Week and Space Technology</u>, April 5, 1976, page 21.

[5]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3214.

the XM-1.[1] The original version of the L2 was estimated to cost $1 million (in constant 1975 dollars) when made in Germany as opposed to $700-750 thousand for the XM-1.[2] Another disadvantage for the L2 was that it would take 26 months longer to produce the first L2AV (in the US) than the first XM-1, assuming the L2AV were selectd by March 1977.[3] While the L2 was roughly comparable to the XM-1 candidates in mobility and firepower, it was judged to provide inadequate armor protection and to be too costly, due importantly to its complex fire control system.

Accordingly, in developing the L2AV Americanized version, the Germans attempted to improve ballistic protection by adding on a German-developed special armor and by reducing production costs, in part, by simplifying their fire control system and utilizing additional US components. In addition, since the L2 utilized a 120mm main tank gun, the L2AV had to be modified to carry the 105mm gun required by the US (by utilizing the 105mm turret from the German Leopard I tank). The weight of the added armor forced modifications in other areas (e.g., the suspension system). Since only 18 months were available to develop the L2AV, there was no time to redesign the turret and hull to take full advantage of the special armor and to keep L2AV weight within the required limit.

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1976 Appropriations, Part 4, page 625.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3215.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7020.

The L2AV did undergo the scheduled testing at Aberdeen Proving Ground from September to December 1976 and was said to have met or exceeded most US requirements.[1] Compared to the XM-1, the L2AV was judged to have a slightly more accurate fire control system but a higher cost and less adequate armor protection, compartmentalization, and gun movement.[2] Rather than continue the full-system evaluation scheduled through March 1977, the Germans agreed in January 1977 that the evaluation would consider only selected major L2 components.[3]

While the L2AV was not selected by the US, its 120mm smooth-bore Rheinmetall main tank gun eventually was. A joint evaluation of main tank guns was conducted by the US, the FRG, and the UK between 1973 and August 1975 to evaluate the German 120mm gun, a British 110mm gun and the British-designed 105mm gun that was used widely in NATO and was planned for the XM-1. The trilateral group concluded that the 105mm gun remained adequate for the foreseeable future and should be used on the new generation of tanks (i.e., the XM-1 and L2), while optimal armament for the future should be developed jointly. The US accepted the trilateral recommendations but conducted studies in 1976 to determine the impact of incorporating a 120mm gun into the XM-1 in the future. The FRG disagreed and proceeded to develop the L2 with the 120mm gun.

In the interest of NATO standardization and as a hedge against unforeseen future threats, the US and the FRG agreed

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[1] See International Defense Review, January 1977, page 109.

[2] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5068, Part 3, February 7, 1977, page 269.

[3] Continued full-system evaluation would have required continued German expenditures for a competition they had little chance of winning.

in a July 1976 Addendum to their 1974 MOU that the XM-1 would be developed with a hybrid turret capable of accepting either a 105mm or a 120mm gun. The US was to decide by January 15, 1977 which 120mm gun to use, but delayed the decision until December 1977 in order to evaluate properly a British 120mm candidate as well as the German 120mm gun that was chosen in January 1978. The first US production tank with the 120mm gun (the M1E1), is scheduled for production in 1985. The decision to equip the M-1 initially with the 105mm gun and add the 120mm later was based, in part, on the desire to avoid delaying the XM-1 Program and paying the associated cost penalty (due to inflation).[1]

Prior to the July 1976 Addendum, the Army felt that the 105mm gun together with ammunition improvements being developed was more than adequate to meet the foreseeable Soviet threat. It was recognized that the 120mm was a bigger gun and could achieve a given degree of target penetration at twice the range of the 105mm gun[2], and that the 120mm gun would be inherently superior at defeating advances in Soviet armor protection and could match the range of the 120-125mm guns on the Soviet T-72 tanks.[3] However, the US had disagreed with Germany over the importance of range and the prospects

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7017.

[2]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 9.

[3]See International Defense Review, June 1976, page 989.

for Soviet armor improvements.[1] Further, the larger 120mm round would force a reduction in the number of rounds carried by the XM-1 (from 55 to 40)[2], thus reducing the effectiveness of the tank system. Also, due to the widespread NATO use of the 105mm gun, using the 120mm gun would initially decrease NATO standardization. Since the 120mm gun was also heavier and more expensive and since the 105mm gun appeared more than adequate for at least ten years, the Army decided to continue with the 105mm gun.[3]

Following the July 1976 Addendum and the selection of the German gun in 1978, the Army defended its use of a 120mm gun as follows:

> As we said earlier, for anything we shot at, anything that could reasonably be built by our armor experts, there was no question in any of our minds that the 105 was adequate. Then we had to apply judgment about this fast moving technology and decide whether we ought to buy an R&D hedge for the future to give us more gunpower if something materializes that we simply cannot predict.[4]

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[1]Germany viewed the tank as a long-range defensive weapon. The US planned to use antitank missiles for the defensive role, and believed that European terrain would restrict 95 percent of target acquisitions to less than 3000 meters. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7036.

[2]See International Defense Review, December 1981, page 1664.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7026.

[4]See Committee on Armed Services, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 1, February 7, 1978, page 624. Questioners at the same hearings suggested that the gun decision was imposed on the Army by OSD for political reasons and was related to the German purchase of the US AWACS.

The German gun was chosen over the British 120mm gun in part because there would be more German than British tanks on the Central Front and since the L2 was likely to be purchased by other NATO allies.

Adoption of the 120mm gun did require some XM-1 design changes. On January 15, 1976, the Secretary of Defense directed that the XM-1 be designed so that only the turret would have to be changed in order to accommodate the 120mm gun.[1] The contractors studied the potential impact so that necessary changes could be incorporated into their FSED proposals. Their chassis were basically able to carry the additional 1600-2000 pound weight expected, but changes might be required for the ammunition and fuel storage, stabilization, turret drive, gun mount, and shield. The July 1976 Addendum required that the XM-1 turret be redesigned to accept either the 105mm or the 120mm gun. The hybrid turrets were designed (including mock-ups) by the contractors after the DT/OT-1 and included in their final FSED proposals.[2]

The source selection process itself was delayed in a related action. The July 1976 Addendum to the 1974 MOU with Germany called for harmonization and standardization of major

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 7022-7037.

[2] The only changes necessary to incorporate the 120mm gun into the FSED design thereafter were to be changes to directly affected hybrid turret components, such as the main and coaxial gun mounts, the feed system, and the ammunition racks. See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 46.

components between the XM-1 and L2 tank systems.[1] As already noted, the Addendum committed the US to designing a hybrid turret and eventually to utilizing the 120mm gun. Prominent among the remaining components considered was the turbine power package (i.e., engine and transmission) that Chrysler had selected for its design. The FRG agreed to incorporate the US turbine power package after the US had incorporated it and certified that it would meet unique German requirements.[2] During the interim the Germans would utilize their diesel power package for the L2 and the US was free to utilize a diesel initially on the XM-1 if desired. The Addendum was negotiated during June 1976 and by July 20, 1976, the Army advised the Secretary of Defense of the winner of the XM-1 competition. However, while OSD had anticipated that the competitive proposals would price options for the hybrid turret and for utilizing either power package (i.e., GM's diesel or Chrysler's turbine) in either contractor's tank,[3] the proposals actually priced only the contractors' own power packages and were based on a turret for the 105mm gun.[4] Rather than to accept the source selection result and

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[1]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 28-38 for the text of the Addendum.

[2]In fact, Germany eventually decided not to utilize the turbine. See International Defense Review, December 1981, page 1657.

[3]The AD development contracts gave the Government rights to technical data and announced the Government's intention to consider technical transfusion between the competing designs during negotiations for the FSED contract. See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 134.

[4]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 24.

negotiate the changes on a sole-source basis as the Army preferred, the SECDEF directed that the source selection be delayed for up to four months so that the contractors could submit competitive proposals for various alternative configurations. As the Deputy Secretary of Defense testified:

> I was unalterably opposed to making these changes in a sole source environment after the contractor was selected. I wanted to know what those unit costs were, what the delays in the program might be, if any, and have those costs determined competitively between the two contractors.

He also testified that:

> ...standardization was not the central issue in the decision. Indeed, the delay of a few months would have been required in any case.[1]

Thus, the interchangeability of power packages between the competing XM-1 designs would evidently have been an issue even without the Addendum. Nevertheless, the revised RFP explained the changes as follows:

> The Government desires to consider an alternative proposal which will incorporate requirements in furtherance of the US/FRG agreement and NATO standardization.[2]

For the delayed source selection, GM was required to submit a proposal including the turbine power package while Chrysler could decide whether to propose a diesel version. In agreement with the Addendum, the alternative XM-1 proposals were also asked to consider metric fasteners and the L2's

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[1]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 22.

[2]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 46.

gunner's auxiliary telescope. The final contractor offers would be due by October 28, 1976, with source selection scheduled by November 17, 1976.

C. COMPETITIVE INCENTIVES TO CONTROL COST

1. Value of Winning

Were the contractors strongly motivated to win the competition? The company selected would receive a major share of an R&D and procurement program then estimated at more than $5 billion, mostly to be negotiated in a sole-source environment.[1] Of course, this was not a large amount compared to the total revenues of GM and Chrysler over the same time frame, but it would be noticeable at the division levels where the contractors' project organizations were established, namely the Detroit Diesel Allison Division of GM and Chrysler's Defense Division. In addition to US Government sales, there would be prospects for foreign military sales of the M-1. Continuing efforts toward NATO standardization held out a slim chance that the UK or the FRG would buy the M-1. While those hopes did not pan out, the Dutch negotiated seriously for the M-1 between 1977 and 1979 before choosing the L2, in part due to economic and political considerations.[2] The Swiss similarly tested and evaluated two M-1 vehicles between 1981 and 1982 before selecting the L2.

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[1] Based on Selected Acquisition Report (U), December 1982. SECRET. Information derived for this study is Unclassified.

[2] See Committee on Appropriations, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, Arpil 4, 1979, page 752.

According to the Army, the contractors acted as though they wanted to win:

> Both contractors are giving the XM-1 program a high degree of emphasis...I feel that both contractors have their best talent on this program.[1]

The contractors were said to be very cooperative contractually during the AD phase and remained motivated during the four-month extension of the source selection process. According to the PM:

> It is my assessment that both contractors are still very much dedicated to winning the competition and are putting a full effort into it.[2]

2. Credibility of Contractors

Did the contractors have good reason to view each other as worthy opponents? It certainly seems so. For its part, GM was a well-managed major corporation with extensive internal resources and talent. GM had been the development contractor on the MBT-70/XM-803 Program and had fabricated six prototype systems.[3] Thus, GM had hands-on experience with state-of-the-art tank technology including particular components that would be incorporated into the XM-1. Chrysler was also a large company relative to most defense contractors and, thanks to

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3231.

[2]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 95.

[3]The XM-803 was an excellent tank from a technical viewpoint. It was cancelled because it was too costly and because the Army's requirements were changing. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1972 Appropriations, Part 6, June 1, 1971, page 521.

the ongoing M-60 Program, had considerable recent experience producing tanks. Further, the Army gave Chrysler access to the XM-803 technology and to particular skills that GM had practiced during the XM-803 Program, such as the welding of rolled homogeneous armor.[1] Further, Chrysler was in the process of utilizing technological advances to improve upon the M-60A1 tank, resulting in the M-60A2 and M-60A3 versions. Also, both GM and Chrysler provided contractual support to the Army during the 1972 reevaluation of tank requirements.

As the competition progressed, public comments by the Army suggested that both contractors were doing well (and hence remained credible threats). For example:

> Chrysler Corporation and General Motors are involved in a real horse race, the winner of which will be a tough competitor for the Leopard 2 design.[2]

The four-month delay in the source selection and the request for new and alternative proposals as discussed above served to heighten the intensity of the competition. A clear winner had been selected but not announced, yet now each firm had additional time to improve on its design and cost proposals. If a firm thought it had initially lost, it would have a strong motivation to improve on its proposal. Thus, it would be risky for a firm that thought it had initially won to stand pat. The Army never announced (and it is not known) which contractor was selected in July 1976. At the time, however, Aerospace Daily reported that GM had won due to lower costs, and Congressman Stratton observed that everybody in

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[1]The M-60 armored structures were formed by casting.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 6984.

Washington was saying that GM had won.[1] The rationale for the delay also seems to imply that GM had won, that is, the delay seems to have been initiated primarily to obtain a competitive bid for the GM design but substituting a turbine for GM's diesel power package.[2] As the PM remarked:

> There has never been anything that says that we might not want to put the turbine engine in the General Motors vehicle and select the General Motors concept. That has been a part of the program planning throughout.[3]

Even if GM were not actually the July winner, the indications cited above would have put a great deal of pressure on Chrysler to improve its proposal.

3. Importance of Cost among Program Objectives

Should the contractors have expected unit production costs to be important to the selection of a winner? They certainly should have on the basis of the announced source selection criteria:

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[1] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 7, 48.

[2] The new RFP did not require Chrysler to propose a diesel version of its design, and the engines were the only components involved in the alternative proposals with a sufficiently large cost impact to justify the delay. The hybrid turret was expected to increase unit hardware costs by less than $3000. Further, while the July 1976 Addendum did not require that the US initially utilize a turbine, it did indicate that the US was seriously considering the turbine regardless of which contractor was selected.

[3] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 136.

> In evaluating proposals...the Government will evaluate the areas of (i) Engineering Design/Operational Suitability (ED/OS), (ii) Cost, and (iii) Management. The areas of ED/OS and Cost are of paramount and interrelated importance in the selection. While the area of Management will be evaluated to discriminate among proposals, it is of lesser importance...cost is also significant in that it imposes financial limitations on the basis of which the Government may not be capable of awarding a contract, or of continuing a program, as it simply could not be afforded.[1]

The evaluation factors within the cost area, listed in order of importance, were:

- Average unit hardware cost in production,
- Full-scale engineering development/production engineering and planning (FSED/PEP) contract cost,
- Life-cycle cost.

As the RFP explained, the Government placed the:

> ...greatest emphasis on average unit hardware cost of production vehicles...the Government may favorably consider proposals which may incur greater development costs if this expenditure will achieve a more economical hardware unit cost.[2]

Thus, unit hardware costs would clearly be important to the source selection evaluation.

As noted above, the contractors were given a design-to-unit-hardware-cost (DTUHC) ceiling and were permitted to make trade-offs within bands of acceptable performance in order to remain within that ceiling. If the minimum performance requirements could not be achieved within the DTUHC ceiling,

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[1]Based on Request for Proposals, DAAE07-76-R-0491, March 4, 1976, page D-1.

[2]Ibid., page A-6.

the contractors were to identify the DTUHC impact of reaching those minimums. In addition, the RFP stated:

> Alternative proposals to the basic XM-1 Tank System may also be submitted identifying system alternatives that would offer marked improvements to the requirements at a modest increase in the design-to-cost or minimal decreases in requirements with substantial reduction in the design-to-cost, contract cost or life cycle cost.[1]

Once a system was designed that met both the DTUHC ceiling and the minimum performance requirements, the Army did not specify whether further efforts should seek to improve performance or reduce unit costs. The Army's preference would depend on what kinds of improvements were possible.

In Congressional testimony, however, the Army often spoke as though the objective were to maximize performance subject to the DTUHC ceiling. For example, the PM testified:

> But, we made clear that we wanted a tank submitted that was within the cost ceiling, and if necessary, he should trade off below the performance bands in order to stay within that cost ceiling. ... we were looking for the best tank, as a system, that we could get for the price we had set forth.[2]

In fact, the contractors are reported to have adopted different strategies, with Chrysler seeking to maximize

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[1] Ibid., page C-4.

[2] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 120.

performance at the DTUHC ceiling and with GM attempting to reduce unit costs below the ceiling.[1]

4. Validation of Cost Estimates

What assurance did the Army have that the contractors were taking the DTUHC ceiling seriously and that it could be met once the XM-1 entered production? The PMO made a serious effort to validate the DTUHC estimates through in-depth reviews of the contractors' procedures and estimates:

> The current basis for our cost estimates is the current design configurations, with vendor quotes and manufacturing hardware estimates at the lowest practical hardware work breakdown structure. These are firm estimates based in part on prototype construction experience and competitive quotes on "buy" items. Labor estimates are based on prototype construction experience modified by detailed manufacturing processes analyses to account for quantity production.[2]

The Army further observed:

> The construction of complete prototypes gives the Army increased confidence in the validity of the contractors' cost and performance estimates.[3]

Thus, the review procedure was thorough and based on fact.

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[1]Based on personal interviews at the M-1 PMO and at General Dynamics Land Systems (GDLS) Division. The contractors and the PMO were unable to get higher officials in the Army or OSD to endorse either approach.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1974, page 3220.

[3]Ibid., page 3222. The integration of subsystems during the AD competition was particularly helpful in this regard.

5. Priced Production Options

Throughout the competitive AD phase, the Army's announced intentions for the FSED phase proposals did not include priced production options. Instead, an award fee would be attached to good performance in realizing the DTUHC goal during the FSED phase. Then, at the last minute, the Army imposed a requirement that the FSED proposals include firm ceiling prices for production options for the first two years, namely for 110 units for FY79 and 352 units for FY80.[1] The PM explained the imposition of the ceiling requirement as follows:

> The purpose of that was to provide a better basis on which to judge the credibility and the realism of the costs that we were to receive from the contractor as far as the unit cost of the tank. What this was addressing was asking them to give a specific cost estimate on the initial production vehicles. This, then, by use of the learning curves, would enable us to track the design to costs that we had worked with them on over a three-year period more accurately against what the first cost would be of the vehicle.[2]

The ceiling prices would not be evaluated separately during the source selection, but would be used to validate the DTUHC estimates which would be evaluated.[3]

The production option proposals specified the fixed ceiling prices but the cost and profit targets and sharing

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[1]The best and final offers (BAFOs) were originally due May 25, 1976 and the ceiling price requirement was imposed in March 1976.

[2]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 123.

[3]The RFP required that the ceiling prices not exceed the unit hardware costs tracked during the AD phase, allowing for requirements changes.

arrangements for the FPI production contracts were to be negotiated at the time the options were exercised. The ceiling prices would be subject to adjustment to reflect economic fluctuations (i.e., inflation) and changes initiated by the Government or due to Government-furnished equipment (GFE). The ceiling prices, however, covered only recurring hardware cost (less engineering support to production (ESP)) for the production systems, and excluded spare parts and the costs of equipping the Government-owned production facilities. The proposal evaluations were to consider contractor estimates of Government facilitization costs based on reasonably detailed planning of plant layouts and production equipment requirements by the contractors. This would provide some protection against the winning contractor making excessive demands in the future for costly production equipment as a means of controlling recurring hardware costs within the price ceilings. However, no firm ceiling was proposed for facilitization costs and no definitive facilitization plan was established.[1]

While the ceiling price requirement for recurring hardware cost had not been anticipatd by the contractors during the AD, the DTUHC reviews and estimates provided them with a reasonable basis on which to determine their ceiling

[1]Discussions with PMO officials suggest that a firm ceiling for facilitization costs would have imposed unacceptably large risks on the contractors In addition, the Army had not yet finalized its production location plans.

price proposals.[1] In addition, at least one of the competitors was able to control its risks by locking its major subcontractors (representing 50 percent of contract costs) into firm price ceilings under the same terms and conditions as the Government required before it submitted its proposal for the production options. As noted above, contractor risks were also controlled by exclusion of nonrecurring facilitization costs from the ceilings. In addition, the proposals included a clause obligating the Government to fund adequately to provide the necessary facilities, giving the winning contractor some assurance that its recurring costs would not exceed the ceilings due to insufficient or inefficient production equipment. Thus, the contractors were willing to propose ceiling prices even though it would be two and a half years before the first production option was exercised and much longer before the work itself was completed.

It should be noted, again, that the delay in the source selection to November 1976 was largely motivated by DoD's desire to extend the ceiling prices to cover additional system configurations not considered when the initial ceiling prices were proposed in July 1976. As the Deputy Secretary of Defense observed:

> I don't think there is any question whatsoever that by doing this [i.e., obtaining proposals for alternative configurations] in a competitive environment they are going to get better proposals

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[1]Discussions at GDLS suggest that, for Chrysler, the DTUHC estimates provided an adequate basis except for taking into account particular contractual terms and conditions. Another limitation was that the DTUHC estimates emphasized average costs over the total planned buy rather than the higher costs associated with learning and starting up for the first two years.

from the contractors with respect to both price and delivery and innovations, as opposed to doing it under a sole source environment.[1]

6. Competition during Follow-on Procurement

Did the contractors have reason to believe the Army might reintroduce tank competition during the production phase, and thus reduce the incentive to buy-in for the two production options? While dual-sourcing of production was always a possibility and was discussed at various times, there were no specific plans during the AD phase to do so. Early in the FSED phase, the Army's Deputy Chief of Staff commented:

> I think an even better idea is to have General Motors compete for all or part of the follow-on production after full scale engineering development has been completed by Chrysler and we have a complete data package.[2]

He went on to observe that while the Army's Lima, Ohio plant was to be used for initial M-1 production, the Detroit Tank Plant could eventually be used by General Motors as a second source. The idea had been discussed with the Army staff, but not with General Motors. The Assistant Secretary of the Army also referred to the availability of two sites for XM-1 assembly:

> We wanted to hold open, if only slightly, the possibilty of competing and be in a position where there is a cost level beyond which we would not go with the current contractor. The two sites do give

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[1]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 18.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5068, Part 3, February 7, 1977, page 271. The technical data package was expected to be available by November 1979, although additional design changes were likely.

> us some measure of protection in negotiating the follow-on contracts for the first two years, but it is not great.

But the XM-1 PM observed:

> Being as candid as I can, I think the opportunity for somebody to move in and take the XM-1 program away from a prime contractor once he has designed it, once he is at the top of the learning curve with his people, with his force, his management team, is remote.[1]

As it turned out, the Detroit and Lima Plants were facilitized to produce different parts for each other, with both plants assembling complete tank systems. Only Lima could fabricate the hull and turret while only Detroit produced some 63 other parts. In June 1982, the Army determined that it would then cost some $400 million to enable both plants to stand alone (and hence support dual production contractors).[2]

During the AD phase, the Army initially intended co produce at the Detroit Tank Plant. But by early 1976 (i.e., before the BAFOs for the July source selection) the Army was studying the possibility of utilizing its Lima facility instead. On August 9, 1976 (i.e., before the BAFOs for the November source selection), the Army announced that it would facilitize its Lima plant for initial production and probably also produce at Detroit after M-60 production was phased out. Thus, the contractors were aware that two tank plants

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 5, April 6, 1978, page 372 for this and the preceding quotation.

[2]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 13, 1982, page 758. The cost would have been much less if the plants had been made independent from the start.

would be available if the Army should decide to dual-source follow-on production.

Finally, the Leopard 2's existence may have put some additional pressure on the XM-1 competitors. But, as discussed above, the L2's prospects in the September 1976 to March 1977 evaluation were not strong and the start-up costs to produce the L2 later would be prohibitive once facilitization costs for the XM-1 were sunk.

7. Correction of Design Deficiencies

Because of the firm production price ceilings, and also due to the award fee in the FSED contract for DTUHC performance, the winning contractor would be under considerable pressure to control unit hardware costs for the FY79 and FY80 buys and hence would be motivated to utilize lower-quality components than might otherwise be the case.[1] Further, the contractor would retain configuration control during FSED, in part to give the contractor flexibility for a continuing design-to-cost effort. In addition, the planned concurrency of low-rate initial production (LRIP) with the end of FSED increased the risk that corrections to design problems would necessitate costly retrofits to production tanks. Accordingly, the Army took advantage of the competitive environment and required that the contractors propose correction-of-deficiencies (COD) clauses.[2]

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[1]Controls already existed to prevent the contractors from using clearly inferior components. But, as discussed in Section D, the design-to-cost emphasis could be expected to reduce over-engineering and hence increase the risk that acceptable components would later prove to be inadequate.

[2]Discussions at the PMO emphasized that the COD would be a desirable feature even without the DTUHC emphasis.

The COD would require the winning contractor to correct deficiencies in the M-1 Tank System that prevented it from satisfying its contractually specified performance and other requirements.[1] Correction would include necessary design changes as well as hardware changes for new and previous production systems for deficiences discovered within 12 months of the final delivery under the production options, provided the deficiencies were not caused by the Government. The contractor was required to propose a specific target cost for COD with costs to be shared under the FPI production contract but within the same firm ceiling prices discussed above. Thus, the COD would provide an incentive for the contractor to prevent design deficiencies as well as an additional means of limiting unit costs. As the PM explained the COD:

> That helps us two ways: It is a very positive incentive right now to fix the problem and, second, once that tank gets in the field it becomes even more expensive and the contractor has to bear the responsibility for those problems that are design problems.[2]

8. Summary of Competitive Incentives

The AD competition was structured so as to put considerable pressure on the contractors to control unit hardware costs. In the first place, the competition matched two well-qualified contenders and indications throughout AD were that both remained very much in the running. Further, the Army made it very clear that cost would be given as much

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[1]Based on Request for Proposals, DAAE07-76-R-0491, March 4, 1976, Attachment 9.

[2]See Committee on Appropriations, House of Representatives, Hearings on Military Posture and H.R. 1872, Part [illegible], April 4, 1979, page 740, 741.

weight as technical performance in the source selection evaluation, and insisted that the contractors propose systems that satisfied a stringent design-to-unit-hardware-cost (DTUHC) ceiling. In order to assure that the contractors' designs would indeed satisfy the DTUHC ceiling, the PMO conducted regular and thorough DTUHC reviews during the AD phase. Cost validation was also aided by the integration of almost all contractor-furnished subsystems in the competitive prototypes. The Army required that the contractors propose firm price ceilings for recurring hardware costs under options for the first two production awards. The requirement for ceiling prices was imposed on the contractors at the end of AD, too late to have much influence on their design configurations for the July 1976 source selection. But the requirement may have had more influence on proposals for the second source selection in November 1976, and provided a strong motivation for the winning contractor to continue to control unit costs during the sole-source FSED phase. A potentially important weakness in the incentive structure was that the ceiling prices covered only recurring hardware costs and did not include production facilitization or spares and repair parts. The decision to hold a second source selection brought additional pressure to bear on the contractors' cost proposals, particularly if either contractor perceived itself to have lost the first selection. The parallel evaluation of the costly German Leopard 2 Tank System probably imposed little additional pressure on the XM-1 contractors. There were no serious plans to reintroduce competition at the system level during the production phase, although the possibility was discussed and the contractors were aware by the end of AD that the Army planned to have two tank assembly plants available. Finally, the contractors were required to propose correction-of-deficiencies (COD) clauses for the

Finally, the contractors were required to propose production options, thus limiting the Government's costs for correcting design problems and providing the contractors with an incentive to avoid excessive design risks when controlling unit hardware costs.

D. RESULTS OF THE COMPETITION

1. Source Selection

On November 12, 1976 (as indicated on Table B-4), the Army announced that Chrysler had been selected for the award of the sole-source FSED contract. A 36-month FSED/PEP phase was planned, including the fabrication and testing of 11 additional prototype systems. The FSED phase would overlap by six months the start of the FY79 LRIP production option. The FSED contract was a CPIF type with an award fee of up to four percent of target cost for DTUHC performance.

The source selection process attempted:

> ...to select that tank system and contractor which have the best possibility of achieving production....of a tank meeting the Army's performance requirements...at affordable and reasonable costs of development, acquisition and ownership within the overall development schedule.[1]

The evaluation considered contractor proposals, the DT/OT-1 test results, and other information. Prototype deficiencies identified during DT/OT-1 were not counted against the contractors provided they could obtain approval of the Source Selection Evaluation Board (SSEB) for proposed fixes. In fact, extensive changes from the prototype designs were

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[1]Based on Request for Proposals, DAAE07-76-R-0491, March 4, 1976, page D-1.

Table B-4. CHRONOLOGY OF LATER PROGRAM EVENTS

DATE	EVENT
July 1976	Initial Source Selection
July 1976	Addendum to 1974 MOU with FRG
September to December 1976	Comparative Testing of Leopard 2
November 1976	FSED Contract Awarded to Chrysler
February 1978 to September 1979	Development Test 2
April 1978 to February 1979	Operational Test 2
April 1979	DSARC 3 Approves Low-Rate Initial Production (LRIP)
May 1979	LRIP Contract Awarded
November 1979	FSED Ends
February 1980	Delivery of First Two LRIP Tanks
October 1980 to September 1981	DT/OT-3
January 1981	Initial Operational Capability (IOC) Achieved
November 1981	DSARC 3A Approves Full-Scale Production
March 1982	Chrysler Defense Acquired by General Dynamics
November 1982	Production Rate Reaches 60/Month
August 1985	First M1E1 Production Expected.

included in the FSED proposals.[1] In addition to deficiency corrections, the changes reflected DoD's desire to consider various alternative versions of each contractor's tank, which was responsible for forcing the second source selection in November. The contractors thus were required by October 28, 1976 to propose versions with hybrid turrets and other potential NATO standardization items, and GM was required to propose a version of its design powered by the turbine engine used by Chrysler.

It can be presumed that cost came into play for the actual source selection, since the competing designs were closely matched from the standpoint of overall technical performance. In describing the DT/OT-1 test results (before the tests were completed or evaluated) the PM observed that it appeared as though both contractors would meet mobility, armament, and fire control performance requirements (although there had been some tuning problems in the fire control area), and

> that both contractors have built outstanding tanks and the choice between them will be a difficult one.[2]

After the source selection and considering both the tests and the contractor proposals, the Assistant Secretary of the Army noted:

> ...the expectations and the specifications in terms of performance were met or exceeded by both candidates. Either one of the candidates is a far superior tank to the M-60. It was a close

[1]For example, discussions at the PMO indicate that Chrysler was able to improve armor protection substantially in its proposal.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1977 Authorizations, Part 12, April 6, 1976, page 6987.

horserace. I think the Army came out the winner as far as having competition of this kind all the way down to and including the field testing of prototypes.[1]

Perhaps the most dramatic difference between the competing designs was that Chrysler used the Avco-Lycoming AGT-1500 regenerative gas turbine engine while GM utilized the Teledyne-Continental 12-cylinder AVCR-1360-2 turbo-supercharged diesel engine. Both were powerful, 1500-horsepower engines. The Army had begun development of the AGT-1500 in the mid 1960s and it had been considered for use in the MBT-70. Although not so used, the Army continued to fund its development in a parallel program. The AGT-1500 was relatively immature but did not represent an advancement in the state-of-the-art for turbine engines. When Chrysler selected it, no turbine had been used as a primary power source in a combat tank, but turbines had powered commercial trucks and Greyhound buses. Until the AGT-1500 proved itself in the DT/OT-1 testing, there had been considerable scepticism over whether it was suitable or ready for tank use.[2] While diesel engine technology was relatively mature (and well-established for tank use), the AVCR-1360-2 was a new and impressive development. It was based on the AVCR-1100 engines that had been proposed for the MBT-70 as well as the new

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5068, Part 3, February 7, 1977, page 267.

[2]For example, there was concern over whether the turbine could perform amid the dirt of the ground environment. See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 16.

diesel being developed for the M-60A3 improvement.[1] The AVCR-1360-2 produced twice the power of the 750-horsepower M-60A1 diesel yet was smaller and lighter, due in part to its advanced variable-compression-ratio pistons.[2] The new diesel was somewhat more mature than the turbine in terms of hours tested, but both would require more development work.[3]

Each engine had certain advantages over the other, so the choice between them was not obvious.[4] The principal advantages for the AGT-1500 turbine included:

- Smaller size: The turbine engine weighed some 2000 pounds less than the diesel, giving Chrysler a great opportunity to improve its armor protection without exceeding the maximum tank weight limit. Including its large air cleaner, the turbine occupied only 2.42 cubic yards of space, barely half the volume of the diesel.
- Power: While both engines were rated at 1500 horsepower, the turbine absorbed less of this total for cooling purposes (30 versus 160 horsepower) and thus provided greater net power. Further, the turbine was thought to have a greater horsepower growth potential (to 2000 as opposed to 1800 horsepower for the diesel).

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[1]The AVCR-1100 was rejected in favor of a German diesel for the MBT-70, but was utilized (in its 1250-horsepower configuration) for the XM-803.

[2]See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 166.

[3]For example, at the end of the AD phase it was estimated that additional R&D funding of $40 million would be required for the diesel compared to $90 million for the turbine. The schedule risk for the turbine also appeared to be higher. See International Defense Review, March 1980, page 318.

[4]The comparative data in this discussion are taken from International Defense Review, March 1976, page 481-484, Armor, January 1977, page 31; International Defense Review, March 1977, page 459-468; and March 1980, page 318.

- Performance: The turbine provided greater acceleration than the diesel (the time from 0-20 mph for the AD prototypes was 7 seconds for Chrysler versus 8.2 seconds for GM). In addition, the turbine was much quieter and emitted virtually no exhaust smoke (hence reducing detectability). It was also said to start more easily in cold weather, maintain performance better in hot weather, and operate on a wider range of fuels.
- Life Cycle Costs: The turbine was thought to have greater potential for growth in reliability and durability than the diesel and hence could achieve lower support costs. The turbine configuration was much simpler, including 31-percent fewer parts and 62-percent fewer critical parts. The turbine would be more durable than the diesel (time between overhauls was predicted to reach 1000 hours for the turbine versus 650 hours for the diesel). Turbine oil consumption would be dramatically less, and a modular design would reduce the need to stock and replace whole engines.

At the same time, the AVCR-1360-2 diesel had certain advantages over the turbine:

- Price: The acquisition cost of the diesel was lower (and the turbine would have to reach its full RAM-D potential in order to offset this advantage).
- Fuel Consumption: The diesel consumes less fuel than the turbine and hence a diesel-powered tank would require less fuel storage to achieve the required range. The difference in fuel consumption has been estimated to be as great as 20 percent although recent estimates place the difference closer to 5 percent[1]
- Performance: The diesel was thought by some to be more suitable to operation in a dirty ground environment.

Thus, the choice between the turbine and the diesel would be difficult. For example, when asked whether the turbine had

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 713-737.

proven itself clearly preferable to the diesel, the PM responded:

> No, sir, I don't believe that. I think both the diesel and the turbine performed well. In acceleration and overall cross-country speed the turbine did perform better, I'll acknowledge that. But in an overall sense there wasn't that much differential in performance.[1]

Further, the degree to which the turbine might achieve life cycle cost savings to offset the diesel's lower acquisition cost was dependent on whether the turbine achieved its promised growth in such factors as mean time between overhauls.[2]

The turbine's prospects were given a powerful boost by OSD's desire to achieve an agreement with Germany to promote standardization of tank components. As discussed above, the July 1976 Addendum with the FRG committed the US eventually to utilize a 120mm gun. In return, the Germans promised to incorporate the US turbine eventually in the Leopard 2. The Germans accepted the turbine because it was the way of the future and that permitted a standardization agreement to be

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[1] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 143.

[2] At the time of the decision, demonstrated mean time between overhauls was still about equal for the two engines. See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 16.

struck.[1] Without such an agreement, according to the Assistant Secretary of the Army:

> ...I think the Army attitude was that we'd like to continue the turbine development program and keep looking at it. If it proved sufficiently promising in our minds at some point that we would make a changeover.[2]

While the source selection was delayed for four months (among other reasons) to force GM to submit a competitive bid including the turbine, a Government preference for the turbine would still have tended to improve Chrysler's prospects. That is, Chrysler had designed its tank around the peculiar characteristics of the turbine and GM had only two months to think through the same problem.

There were many less dramatic differences in the Chrysler and GM designs, including:

- Profile: The Chrysler design was somewhat longer, lower, and narrower.
- Suspension: Chrysler utilized a torsion bar suspension with seven 25-inch road wheels per side and a steel track with integral rubber pads; GM used a hybrid torsion bar/hydropneumatic suspension with six 31-inch road wheels per side and with tracks with replaceable pads.
- Stabilization: The Chrysler gunner's primary sight (GPS) was independently stabilized in elevation only, while the GM GPS was independently stabilized in both elevation and azimuth.

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[1] See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 65. Nevertheless, the Germans eventually decided not to utilize the turbine, in part because it failed to meet "specified unique" FRG requirements for fuel consumption.

[2] See Committee on Armed Services, House of Representatives, Hearings on Delays in the XM-1 Tank Program, August 10 through September 21, 1976, page 204.

Many components were common between the competing configurations, including the transmissions[1], certain fire control items, and the Government-furnished armament.

2. Design Decisions to Control Production Costs

Section C above indicated that the competitive AD was structured in such a way that the contractors had strong incentives to control expected unit hardware costs, and especially to meet the design-to-unit-hardware-cost (DTUHC) ceiling of $507,790 (in constant 1972 dollars). By the end of the competitive AD phase, the contractors were estimated to have kept recurring unit hardware costs below the DTUHC ceiling. This section considers some of the particular configuration decisions made by the contractors in order to control production costs.

The most dramatic savings were achieved in the fire control system (FCS). For the more expensive XM-803, the FCS had accounted for some 43 percent of unit costs, while the original DTUHC ceiling for the XM-1 allocated only 23 percent to the FCS.[2] Thus, the Army had already reduced its FCS requirements and expectations. But the intense AD competition and increases in unit hardware costs in other areas motivated the contractors to achieve even greater savings, and the evolution of the technologies involved helped to make such savings possible. To a large extent, the contractors were required to meet performance specifications (e.g., for firing accuracy) but were free to select equipment that would achieve the desired results. In addition, they were allowed to trade

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[1] Both used modified versions of the Allison X-1100 transmission.

[2] See International Defense Review, March 1977, page 461.

off certain characteristics in order to reduce costs. The net result was that by the end of the FSED phase the FCS was expected to account for only 14.5 percent of unit hardware costs and (in constant dollars) the FCS cost only 64 percent of the dollar amount originally allocated.[1]

To some extent, FCS savings were achieved through slight reductions in performance that were more than offset by the resulting cost savings.[2] Nevertheless, the FCS met or exceeded its performance requirements. The line-of-sight stabilization for the gunner's primary sight (GPS) provides one example of a cost-saving trade-off. Both the GM prototype and the L2 included GPS sights that were independently stabilized against disturbances in both horizontal and vertical directions (to aid the gunner in holding the sight on target). But Chrysler chose a hybrid method:

> Analysis...showed that the contribution of vertical axis stabilization to accuracy was three times greater than the contribution made by horizontal axis stabilization. Since most costs are incurred by integration of the horizontal line-of-sight reference, separate systems were provided for gun/sight stabilization in elevation and turret stabilization in azimuth. The performance degradation suffered thereby seems negligible compared to the savings realized. The arrangement provides the required performance and meets the cost goal.[3]

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[1]Based on data provided by the PMO.

[2]For example, the Leopard 2 was said to have achieved slightly better firing results during 1981 tests but its FCS was 15-20 percent more expensive. See International Defense Review, December 1981, page 1661, 1663.

[3]Ibid., March 1977, page 461.

In 1973, the Army estimated that Chrysler's hybrid stabilization would save $30,000 per tank.[1] Another cost-saving trade-off was to eliminate the commander's independent sight that would have allowed the commander to scan 360° quickly in a surveillance and target acquisition role.[2] Instead, that role would depend on the gunner's primary sight (GPS) which was linked to the turret and rotated more slowly. The commander was provided with a relay extension of the GPS restricted to the same view as the GPS. As another example, the main gun auxiliary telescope articulates when the main gun is raised. While dove prisms would have been more effective at countering the resulting image rotation, Chrysler utilized mirrors instead to reduce costs. Chrysler also utilized a digital computer that provided better performance at much less cost than its analog counterpart (such as was originally proposed by GM.) Important cost-saving design changes were made to the computer itself as well as to the laser range finder. In yet another example, the number of sensors used to provide automatic input to the computer (for consideration in calculating gun-pointing instructions) was restricted. Manual inputs were instead required for information such as tube wear, muzzle reference compensation, barometric pressure and ammunition temperature. While a damped-pendulum sensor provided cant information (i.e., the angle at which the tank was tilted) automatically when the tank was at rest, the vertical gyro to provide dynamic cant and angle of sight was eliminated. Finally, commercial (rather than military specification) electronic components

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[1] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1974 Appropriations, Part 7, September 17, 1973, page 392.

[2] The L2 did include a panoramic periscope for the commander.

were used to a large degree in order to reduce acquisition costs.

Substantial cost savings were also achieved in the suspension area. By the end of FSED, the suspension system cost only half (in constant dollars) what had originally been allocated for suspension in the DTUHC ceiling. The XM-803 had included an advanced hydropneumatic suspension system in order to provide a relatively stable gun platform during tank movement across rough terrain. But to control hardware costs, GM designed a hybrid suspension utilizing high-strength steel torsion bars for three of the six wheel stations (per side) and hydropneumatic units for three (as opposed to a hydropneumatic unit for each wheel station on the XM-803). Chrysler designed an even less costly suspension system relying on high-strength steel torsion bars. The Chrysler system was also said to be less vulnerable and to present less technical risk. In rejecting a full hydropneumatic suspension system for the winning Chrysler design, the Army later observed:

> The XM-1 suspension system has demonstrated that it meets or exceeds all the required specifications. Recognizing that the Chrysler torsion bar suspension performed equally well as the General Motors, hybrid hydropneumatic suspension, spending... approximately $22,000 per vehicle more in production to adapt the (full) hydropneumatic suspension to the present XM-1 is not considered cost effective.[1]

[1] See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 5, April 6, 1978, page 362.

Further, Chrysler opted for a track with integral pads that had a lower acquisition cost--and higher support costs--than GM's replaceable pad track.[1]

Contractor efforts to reduce unit hardware costs for fire control, suspension and other areas constituted only part of the effort to balance cost and performance in the XM-1 design. As discussed above, crew survivability was the top priority performance requirement, placing major emphasis on ballistic protection. But the addition of armor would increase unit costs as well as threaten to breach the Army's 58-ton maximum weight ceiling.[2] Accordingly, cost and weight savings in other areas would be necessary in order to provide better armor protection and improvements in other priority performance areas. Chrysler's use of the turbine engine exemplifies this approach. The turbine's acquisition cost was higher than that of the diesel engine and, as indicated on Table B-5, the unit cost of the engine (adjusted for inflation) was almost three times as high at the end of FSED as the Army had estimated at the beginning of AD. If the turbine's higher acquisition cost could be offset by hardware cost savings in other areas, then Chrysler could design its system around the turbine's performance and other advantages. In particular, the turbine's substantially smaller weight and volume would permit application of

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[1]On the other hand, Chrysler's decision to utilize seven (rather than the six per side used by GM's XM-1 and by the XM-803 and M-60) road wheels added 618 pounds and $800 in unit costs but was expected to improve suspension durability (i.e., to lower support costs) as well as lower the tank silhouette (through smaller-diameter wheels). See International Defense Review, March 1977, page 464.

[2]The ceiling was later increased to 60 tons.

Table B-5. COMPARISON OF UNIT HARDWARE COSTS (IN THOUSANDS OF CONSTANT FY 1972 DOLLARS)

TANK COST AREA	FY 1972 DESIGN-TO-UNIT-HARDWARE-COST THRESHOLD	1979 DESIGN-TO-UNIT-HARDWARE-COST ASSESSMENT
Integration	$ 14.6	$ 51.4
Hull Assembly	62.1	46.3
Suspension	49.5	25.2
Turret	80.1	72.0
(Gun/Turret Drive)	(29.7)	(13.8)
Power Train	96.1	188.1
(Engine)	(41.8)	(121.9)
(Transmission and Final Drive)	(38.8)	(56.2)
Fire Control	119.4	76.0
Armament	46.2	25.6
Other	39.8	26.0
TOTAL	$507.8	$510.6

Source: Based on information supplied by M-1 PMO.

additional armor to enhance ballistic protection. The PM described the central role of armor protection as follows:

> In almost every case the trade-offs... have been principally those associated with weight versus cost in the area of materials. As we have tried to improve the armor areas, in some cases the cost has gone up and we have found production trade-offs that can be made--for example, in the configuration of the engine compartment in the case of one contractor. The other trade-offs that have been made have been a continuing effort to examine the elements of the fire control system....[1]

Weight reduction efforts were also important to permitting armor improvements.[2] While the Army developed the new armor technique and specified the threats that different areas of the tank would have to survive, the contractors were given considerable latitude regarding the shapes and thicknesses of armor to be applied in different areas. This flexibility made the contractors responsible for determining the best levels of armor protection based on the cost and weight trade-offs involved.

The contractor efforts to control unit hardware costs described at the beginning of this section included elimination of some capabilities as well as finding less costly ways of achieving the same, or virtually the same, performance levels. In making these judgments, the contractors were accorded unusual freedom from interference (or help) from Army engineers. Further, the excellent original definition of user requirements and continuing Army self-discipline held the number of requirements changes to a

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1976 Authorizations, Part 6, March 17, 1975, page 3198.

[2]For example, lighter weight metals could be used in noncritical areas.

minimum. Chrysler's DTUHC effort continued into the FSED phase due both to the price ceilings in the production options and the DTUHC award fee and reviews provided for in the FSED contract. Thus, Chrysler retained configuration control and continued to make cost-reducing design changes during the FSED phase. The changes made helped to offset the cost growth normally experienced during an FSED phase.

Overall, the design decisions made in order to achieve the DTUHC ceiling have proved valid. Nevertheless, a few of these DTUHC decisions have been reversed and others remain controversial and might be reversed in the future. The use of some commercial electronic components, for example, led to logistics problems for the Army and the contractor will now revert to military specification components. Also, as the Army reported:

> ...in an attempt to reduce the cost of the engine the manufacturer went to a cast turbine wheel. And this is a lower cost than we would normally use in an engine. And quite frankly, the cast wheel did not prove out. Fortunately, the engine manufacturer has a backup forged wheel which has been placed in the engine now...[1]

Also, in a continuing program to improve turbine engine RAM-D, the Army is conducting a:

> ...reevaluation of configurations not previously pursued for design to cost considerations....[2]

In accord with the DTUHC ceiling, Chrysler selected an hydraulic pump with a unit cost only half that of the

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 677.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorizations, Part 5, May 13, 1976, page 716.

preferred model but then experienced reliability problems. Chrysler chose a $200 truck quality starter for the engine rather than a $2500 aircraft quality starter (or the even more expensive starter of the Leopard 2). The starter was originally viewed as marginally acceptable but has led to excessive downtime and may be replaced.[1] While the Army users originally accepted certain reductions in capabilities at the commander's station, the resulting configuration has been criticized.[2] Future improvement efforts will consider restoration of such features as a commander's independent sight (discussed above) and power elevation and traverse for the commander's machine gun. Use of a dynamic cant sensor may also be considered.

3. Maturity of Phase 1 Design

With the exception of the turbine engine and some changes in Army requirements, changes to the system design proposed by Chrysler for the FSED phase have been relatively minor. Compared to its AD prototype, Chrysler's FSED proposal included some user-directed changes resulting from the Army's analysis of the 1973 Arab-Isaeli War, including additional armor, more main gun ammunition, and substitution of a 7.62mm machine gun for the planned coaxial gun. The FSED proposal also included changes to correct deficiencies identified during DT/OT-1 as well as incorporation of the gunner's night vision system. Finally, the proposals included changes to

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[1]Based on discussions at GDLS. While life cycle costs were considered during source selection, they were given less weight than production costs.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1982 Authorizations, Part 3, May 19, 1981, page 505, 509.

permit later incorporation of a 120mm gun in the interests of NATO standardization, including the hybrid turret and modifications of the internal compartments, turret drive, and suspension.

Changes from the proposed FSED design became necessary later to solve problems emerging during FSED testing.[1] Filters and seals in the air induction unit had to be redesigned to eliminate a dust ingestion problem that caused turbine blade erosion. Track tension was increased and some hardware changes were necessary to prevent a dirt build-up and stop a track-throwing problem. Additional changes were required to eliminate leaks in the hydraulic system, to improve engine fuel control and internal design, and to correct a transmission design flaw that was limiting durability. The M-1 combat weight increased from 58 to 60 tons as a result of earlier changes and the user's 1978 request for additional armor protection.

Following DT/OT-3, only two requirements shortfalls remained.[2] First, the life of the track was tested to be 1056 miles versus a requirement of 2000 miles. The Army did not expect near-term improvements to track durability in light of the state of the art of rubber compound technology. The other remaining problem was a shortfall in powertrain durability. The Army's interim goal was to achieve a 0.5 probability that the engine would last 4000 miles between overhauls, but after

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 720.

[2] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorizations, Part 5, May 13 1982, page 716-728.

a strenuous effort only 0.48 could be achieved.[1] Additional engine design changes are expected as a result of continuing efforts to improve durability and other RAM-D values.[2]

Further design changes are planned for 1985 with implementation of a block improvement program, namely the M1E1 model. The M1E1 will incorporate the 120mm gun, changes to the suspension system and ammunition storage, improved armor, a collective defense for chemical and biological threats, and an air-conditioning system for the crew. The gun and armor changes will increase weight to 63 tons despite a weight reduction program.

4. Tank Production

On August 9, 1976, the Army announced its intention to facilitize its Lima, Ohio plant for M-1 Tank production, with eventual plans to produce M-1s at the Detroit Tank Plant as well. The contractors submitted estimates of facilitization costs as part of their FSED proposals, but these estimates were not binding. In November 1976 (at the time of the source selection) the Army estimated facilitization costs at $866.7 million but by March 1977, Chrysler had proposed costs as high as $1,244 million.[3] Through continuing negotiations and cost-reducing efforts, the Army was able to reduce its estimated

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[1]The turbine was being replaced at 1/2 to 1/3 the frequency of the Army's diesel engines but, based on the original rationale for selecting a turbine, the Army expected ultimately to achieve a 10,000-mile life as opposed to the existing 2800-mile life. See Ibid., page 763.

[2]Production quality control problems at the engine manufacturer had contributed to previous powertrain durability shortfalls.

[3]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 726.

facilitization costs to $811 million by February 1979. Facilitization costs increased thereafter due to inflation and engineering changes and because some tasks required more machine time than had been expected.

To some extent costs were reduced through the use of existing Government-owned equipment but a substantial investment in new equipment was made. Beginning in 1977, the Army expanded its Lima facility by some 28,000 square yards and added a test track. The plan was to facilitize Lima to fabricate the hull and turret structures while both Lima and Detroit would be used eventually to assemble tanks. Some components would be manufactured at the Detroit facility as well as at Chrysler's Scranton plant. Approximately half of the facilitization costs would be incurred at subcontractor plants.[1] Much modern equipment was used at Lima to fabricate the hull and turret structures by cutting, welding, and machining steel plate:

> ... the plant makes extensive use of numerically controlled flame-cutting techniques and automatic welding equipment, as well as Mitsubishi turret-machining equipment and a Cincinnati Milicrom hull-machining line which moves structures from station to station on a cushion of liquid coolant.[2]

The requirement that GM and Chrysler propose firm ceiling prices for recurring hardware costs (for two production

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[1]In addition, Detroit Diesel Allison was induced to invest $20 million to expand its plant based on a Government guarantee to purchase a minimum number of transmissions. See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1979 Appropriations, Part 5, April 6, 1978, page 259.

[2]See International Defense Review, March 1980, page 318.

options) but not for facilitization costs[1] could potentially have led to problems between the Army and Chrysler. Recurring costs clearly depend on the adequacy of production facilities, and explicit trade-offs were made between facilities costs and recurring costs during the FSED DTUHC effort. If Chrysler had made excessive demands for sophisticated production equipment (in order to reduce recurring hardware costs), Government savings from the firm price ceilings might have been dissipated. On the other hand, if the Government had insisted that Chrysler (and its subcontractors) depend too much on less productive equipment (including existing Government-owned equipment) in order to control facilities costs, it might have become impossible for Chrysler to hold recurring costs below its firm ceilings. Despite this potential for controversy, the negotiations for facilities costs referred to above evidently ended successfully.[2]

The production rate was eventually set at 60 tanks per month on a one-shift basis utilizing both Lima and Detroit. Facilitization is planned eventually to permit a multi-shift surge in production to 150 per month. A number of difficulties were experienced in achieving planned production rates. Initially there were delays and learning problems at Lima, particularly in the hull and turret fabrication area.[3] There were also some delays in obtaining the thermal imaging

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[1]Since the tank plants were Government-owned, Government-paid facilitization costs were unusually large for the M-1.

[2]In discussions at the PMO and at GDLS, both the Government and the contractor indicated that disagreements over facilitization did not become a major problem. To some extent, this can be attributed to the DTUHC and production planning efforts that took place during AD.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorizations, Part 5, May 13 1983, page 766.

systems (TISs) due to a shortage of high-quality infrared detectors. But the most persistent problems occurred in the production of turbine engines at Avco Lycoming due to machinist shortages, quality control difficulties and other problems.[1] In the words of AVCO Lycoming's General Manager:

> The products were produced crappy.[2]

5. Subcontractors

To some extent, Chrysler's subcontractors mirrored Chrysler's own efforts to control unit hardware costs. Chrysler established a DTUHC goal for each of its major subcontractors and conducted detailed DTUHC reviews with them. During the AD phase, many of these subcontractors were motivated to control costs by a desire to be on the winning side in the XM-1 competition.[3] Avco, for example, had been developing the turbine for the Army for ten years and stood to grow substantially if Chrysler were selected for the FSED phase. In addition, if Avco could reduce the turbine's high acquisition cost (one of its major drawbacks) there was also a possibility that the Army would decide to use the turbine engine even if GM won the competition. Similarly, Chrysler negotiated with Computing Devices Company (a wholly owned subsidiary of Control Data) for its digital computer. Chrysler winning would have a major impact on this Canadian plant's orders so it was motivated to control hardware

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1983 Authorizations, Part 5, May 13, 1982, page 713.

[2]See The Washington Post, July 10, 1983, page G1.

[3]While all of the subcontractors wanted production contracts, some had such small shares of the total system cost that their efforts to control costs would have little or no effect on the outcome of the competition.

costs. Most of Chrysler's major subcontractors stood to gain if Chrysler won. GM's Detroit Diesel Allison Division, however, supplied transmissions to both Chrysler and GM and hence would benefit regardless of the winner.[1]

The major subcontractors remained motivated to control costs during the FSED phase and the first two years of production because Chrysler required them to commit to firm ceiling prices for recurring hardware costs under the same terms and conditions as the Government imposed on Chrysler. For the third year of production (i.e., FY81), the Army contracted directly with the producers of the engine, transmission, and track and supplied them to Chrysler as GFE. Additional items have been broken out as GFE and multi-year contracts are planned for a number of items. There has been considerable discussion regarding introducing production competition by dual-sourcing major components but a dual-source fire control program has been deleted and Congressional actions may halt plans to dual-source the turbine engine.[2] Nevertheless, these actions indicate continuing Army efforts to control unit procurement costs in addition to the original R&D competition.

6. Cost Results of the Competition

By December 1982, unit procurement cost (UPC) for the M-1 was estimated at $797 thousand (in constant 1972 dollars), 33.9 percent higher than the UPC of $595 thousand estimated at

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[1]Nevertheless, Allison established separate groups to work with the two prime contractors on their particular interface modifications to the common transmission and maintained neutrality between them (based on discussions at GDLS).

[2]See The Washington Post, July 10, 1983, page G1.

the beginning of full-scale development in November 1976.[1] This growth was almost as great as that of the median system without prototype competition discussed in the main report. That median noncompetitive system would have grown 5.8 percent per year or a total of 34.8 percent over the comparable period. Thus, UPC savings as a result of the R&D competition are not immediately obvious.[2]

The M-1 UPC estimate, however, includes the costs of major, Government-directed changes in requirements associated with the M1E1 version that will enter production in 1985. These changes include substituting the 120mm for the 105mm gun together with the block improvement program (BIP) discussed in Section D3 above. The primary vehicle cost of these changes is estimated to be $356.4 million (in constant 1972 dollars) or $50.5 thousand per vehicle (if averaged over the total buy of 7058 tanks).[3] If these costs are excluded, then the UPC estimate has increased from $595 thousand to $747 thousand for a total increase of 25.6 percent. Thus, if the costs of the forthcoming model change are excluded, the M-1 UPC estimate is now 7.3 percent less than it would have been if it had grown at the same rate as UPC for the median noncompetitive

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[1]Based on Selected Acquisition Report, (U), December 1982. SECRET. Information derived for this report is Unclassified.

[2]The UPC estimate is based on assumptions about costs as far in the future as 1990. Nevertheless, it now reflects negotiations for at least four production contracts, two of which were negotiated in a sole-source environment.

[3]Current plans call for 3862 M1E1s and 3196 original M-1s.

system.[1] In escalated dollars, this amounts to a savings of $1.320 billion in M-1 procurement costs. As indicated above, the prototype validation contracts for Chrysler and GM amounted to $157 million, so that a reasonable estimate for the incremental cost of holding the prototype competition is $78.5 million. Thus the UPC growth savings excluding the M1E1 are 16.8 times larger than the incremental costs of the competition. In constant dollars, the ratio of estimated savings to incremental costs is 5.9. If the constant-dollar savings and costs are discounted to reflect the fact that the costs were incurred up front while the savings will be realized in the future (up to 1990), the estimated savings are still 2.4 times as great as the costs.[2]

If competition did help to control the growth of UPC, that would be expected to occur in the area of recurring unit hardware costs.[3] This is the cost segment for which the design-to-unit-hardware-cost (DTUHC) ceiling of $507,790 (in constant 1972 dollars) was established at the beginning of the competitive phase. This is the segment for which the competitors were required to propose firm ceiling prices for the first two production options. As of December 1982, the

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[1]Counting the M1E1 changes, the M-1 Program has experienced procurement cost growth of 11.7 percent (in constant dollars from the development estimate in the SAR until December 1982) due to engineering changes. Since the median competitive program (discussed in the main reports) grew 2.7 percent and the median noncompetitive program grew 4.2 percent due to engineering changes, there is evidence that the M1E1 model change represents an unusually large Government-directed requirements change.

[2]As discussed in the main report, Chapter V, the savings and costs are discounted back to the base year using a rate of ten percent.

[3]Recurring unit hardware costs do not include costs for such items as production facilitization, spares and repair parts, and peculiar support equipment.

DTUHC estimate had increased to $567,700 for a total growth of only 11.8 percent over a period of ten years.[1]

During the AD phase, competition had an important impact on inspiring a successful DTC effort that held recurring unit hardware costs below the DTUHC ceiling.[2] And the firm ceiling prices for the FY79 and FY80 production options, negotiated in the competitive source selection environment, provided Chrysler (and its subcontractors) with a continuing motivation to find cost-saving design changes to offset typical cost growth during FSED and to control costs during the transition to production.[3] Since contract costs reached ceiling levels when production actually occurred, it can be presumed that the ceilings were difficult to achieve and also required some sacrifice of contractor profit. Just before the FY79 option was exercised, the PM discussed the value of the ceiling prices:

> Some people say it is 15 percent, others will tell you it is 25 percent.

Further, without the priced options the Army would:

> ...pay the same amount of money, or darned near, for ten tanks a month as we would pay for climbing up to 30.[4]

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[1]GDLS estimates that, excluding cost growth due to Army-directed program changes, the DTUHC estimate would be $533,400, an increase of only 5.0 percent in ten years.

[2]As noted above, the DTUHC ceiling was a tough one to meet, being substantially below the unit cost of the XM-803 system.

[3]Based on discussions at PMO and GDLS.

[4]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 1872, Part 2, April 4, 1979, page 686, 747. Also note the discussion below regarding the higher prices paid for spare parts.

Nevertheless, negotiations between the PMO and Chrysler proved to be extremely difficult when it came time to exercise the options. As discussed above, the FSED proposals left for future negotiation the specific target costs, and cost-sharing arrangements for the FPI production contracts, and also permitted adjustments for inflation and for Government-directed changes. When Chrysler submitted its proposal for implementation of the options six months before the May 1979 option date, it proposed that the contracts be exercised at the ceilings without even setting a lower target cost. In addition, Chrysler and the Government disagreed over whether adjustments for inflation should be calculated to the midpoints or to the ends of the production periods involved, and over whether the contractor or the Government was responsible for the cost impact of certain design changes, corrections of deficiencies, and production rate changes. As a result, the contractor and the Government were initially some $250 million apart on what the two production options should cost, although the Army expected to negotiate that difference down substantially.[1] The negotiations were tough and acrimonious. On May 7, 1979, following a five-day extension of the option date, the parties still could not reach agreement and so the Army unilaterally set a contract price and exercised the option. The dispute nearly went to court[2] and the first contract was not definitized until September 1980, by which time production deliveries had already been in progress for seven months. The final settlement preserved the ceiling prices and the contractor

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[1]Ibid., page 677,756.

[2]Chrysler did appeal to the Armed Services Board of Contract Appeals on October 11, 1979.

requirements but the Army did accept some of the contractor claims and the impact of inflation on the ceiling prices was substantial.[1]

As discussed above, the production option proposals were required to include correction-of-deficiencies (COD) clauses whereby the option ceiling prices would include the costs of correcting deficiencies (including design deficiencies) in the systems produced under the options. Any failure by the contractor to absorb the costs of covered corrections would represent a loss in the benefits expected from the ceiling prices. The Government identified over 300 COD claims but negotiations to settle these disputes were contentious and the Government was unable to collect on all of its claims. Nevertheless, the COD did provide some substantial benefits.[2]

As noted above, the ceiling prices did not include spares. When the Army negotiated with Chrysler for spares to support the tanks in the first production option, the Army agreed to combine the spares ceiling price (negotiated in a sole-source environment) with the tank ceiling price (negotiated in a competitive environment).[3] This action effectively raised the tank ceiling price because the allowance for cost overruns on the spares contract could now

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[1]The full quantities of 110 and 352 tanks for the two options were acquired, but budgetary problems due to the ceiling increases caused the systems acquired with FY79 and FY80 funds to number 90 and 309, respectively.

[2]Based on discussions at GDLS, the transmission contractor retrofitted clutches on the tanks produced under the first two options at a cost of approximately $5 million.

[3]See Comptroller General of the United States, "Poor Procurement Practices Resulted in Unnecessary Costs in Procuring M-1 Tank Spares."

be used to offset cost overruns on the tank contract.[1] According to the General Accounting Office (GAO), the ceiling prices for spares were overly generous, increasing the likelihood that the contractor would be able to provide the spares at less than ceiling costs.[2] As it turned out, combining tank and spares ceilings turned an estimated $2.6 million loss on the first tank production option into an estimated $3 million profit, in addition to a $3.2 million profit for the spares contract. This discussion exemplifies the difficulties of preserving the benefits of competitively negotiated ceiling prices, but it also dramatizes just how great those benefits can be compared to prices negotiated in a sole-source environment.

The FY81 tank contract was the first to be negotiated in a sole-source environment. Following an intensive Government should-cost effort at Chrysler, Hughes Aircraft and Avco, projected contract costs were some 18 percent below the Army's estimates the previous year.[3] It is not clear how much the Government was aided during the negotiations by information on production experience under the first two options. The

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[1]Under the FPI spares contract, the Government would pay most of the difference between the target cost and actual cost of the spares, up to the ceiling level. Under the new arrangement, if the contractor could achieve the target cost for the spares, the Government's share of the difference between target and ceiling costs for the spares could instead be applied to offset cost overruns on the tank itself.

[2]The ceiling for engines was 44 percent above their estimated cost under the tank contract while the ceiling for transmissions was 63 percent higher than their estimated cost. See Comptroller General of the United States, loc. cit., page 6.

[3]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1983 Appropriations, Part 5, May 13, 1982, page 722.

information was probably useful but may have been unusually distorted by start-up problems and design changes.[1]

The DTUHC effort continued into the FSED phase and had some impact on controlling unit cost growth. The contractor made an effort and was incrementally awarded approximately $5 million out of a potential $7 million award fee during the FSED.[2] The balance of the award fee was not released due to the contractor's high costs in implementing the production options.[3]

The possibility exists that the narrow scope of the competitive ceiling prices actually caused costs not covered by the ceilings to grow more rapidly than they otherwise would have grown. The discussion of the first spares contract provides one example. Also, since recurring unit costs could be controlled by increasing nonrecurring facilitization costs, the ceiling prices could have distorted facilitization decisions. It should also be noted that the costs of armament and other GFE declined (in constant 1972 dollars) from $57,000 per tank in the 1972 DTUHC allocation to $31,000 by the end of the FSED phase. This exemplifies the Army's continuing efforts to control production costs, so that the low cost growth exhibited by the M-1 Program cannot be attributed solely to competition.

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[1]Based on discussions at PMO.

[2]See Defense Systems Management College, "Lessons Learned: M-1 Abrams Tank System," page 18.

[3]Based on discussions at the PMO. The early initiation of production (two and one-half years into the FSED phase) may have prevented a greater DTUHC effort.

Nevertheless, this section will end with one more example of the favorable impact of competition. Before the contractors had submitted their revised proposals for the November 1976 source selection, the Deputy Secretary of Defense discussed the Army's estimate of the additional cost of an hybrid turret able to accept either a 105mm or a 120mm gun, namely:

> ...a range of from zero increase in cost to $4,000 with a probability around $3,000. I think it would be less than that. I think there is a good likelihood that our contractors with their abilities and their innovations could well come in, for any practical purpose with a zero increase in cost by doing this in a competitive environment. Certainly I expect that cost to be less than $3,000.[1]

Following the source selection, the Assistant Secretary of the Army reported:

> There is an added hardware cost of $1,000 per turret...[2]

E. CONCLUSION

The competitive AD phase of the M-1 program matched two well-qualified development contractors and was structured so that the competitors clearly understood that unit hardware costs would have a strong influence on the source selection for the follow-on phase. From the perspective of this study, the M-1 tested two particularly interesting questions, namely:

- Can competitive development lead to unit hardware cost savings in the absence of a requirement for

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[1]See Committee on Government Operations, US Senate, Hearings on Major Systems Acquisition Reform, Part 3, September 29, 1976, page 20.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5068, Part 3, February 7, 1977, page 269.

firm price ceilings to be proposed in a competitive environment?

- What is the impact of requiring such firm hardware price proposals before a system has undergone FSED?

The M-1 experience addresses both of these questions because competitive ceiling price proposals were required, but the requirement was not announced until March 1976, when the prototypes were already in the middle of competitive tests at the end of the AD phase.

With regard to the first question, it is clear that major configuration decisions and cost/performance trade-offs were made by the contractors in 1973 and 1974 in order to satisfy the Army's design-to-unit-hardware-cost (DTUHC) ceiling. For Chrysler, these decisions particularly affected hardware costs for the fire control and suspension systems and largely remain valid today. Still, the full benefit of the competitive DTUHC effort would not have been realized if the ceiling prices had not provided Chrysler with a continuing incentive to control hardware costs during FSED and the first two production buys.

With reference to the second question, the ceiling price requirement provided Chrysler (and its subcontractors) with a strong motivation to realize its DTUHC estimates. Nevertheless, the requirement to propose ceiling prices prior to FSED did create certain problems. For one thing, the scope of the ceiling prices had to be limited to recurring tank hardware costs (excluding, for example, costs for facilitization and initial spares) in order to keep contractor risks within reasonable bounds. In addition, provisions had to be made to adjust the ceilings to reflect inflation and Government-directed design changes during the years before the options would be implemented. Together, the narrow scope and the need to adjust the ceilings led to some very tough negotiations and the benefits of the ceilings were somewaht reduced as a result.

Overall, it is clear that the competition did lead to lower unit procurement cost than would otherwise have resulted. The estimated savings are more than double the incremental costs of competition even when adjusted for inflation and discounted to reflect the time value of Government funds.

Appendix C

SGT. YORK AIR DEFENSE GUN SYSTEM

APPENDIX C

SGT. YORK AIR DEFENSE GUN SYSTEM

A. INTRODUCTION

The Sgt. York Air Defense Gun System underwent a competitive engineering development (ED) program. There was no formal advanced development stage, but the important system concepts had previously been demonstrated and the subsystems utilized were largely mature. The competition ended with a prototype test program (i.e., shoot-off) to validate contractor proposals for a sole-source Phase 2 to complete ED and initiate production. As a result, firmly priced production options covering 45 percent of planned procurement quantities were negotiated in a competitive environment. Thus, the Sgt. York program provides an excellent example of development competition at work.

The discussion in this appendix is organized as follows:

- Section B provides background information on the weapon system, its program history and its acquisition strategy;
- Section C discusses the incentives to control procurement costs provided by the program structure;
- Section D analyzes whether the competitive development actually resulted in the control or reduction of procurement costs; and
- Section E presents concluding remarks.

B. BACKGROUND

1. Mission and System Description

The mission of the M-247 Sgt. York Air Defense Gun System is to provide short-range air defense for maneuvering armored and mechanized units in the forward battle area as well as to provide air defense for convoys and for critical assets in the division area. Secondarily, the Sgt. York will provide ground fire against lightly armored vehicles.[1] The need for a gun system to address this mission was greatly reinforced by a substantial increase in the quantity and quality of the Soviet air support capability. The Soviets had deployed new fixed-wing aircraft capable of low-level, all-weather penetration as well as the Mi-8 Hip-C assault helicopters and Mi-24 Hind attack helicopters armed with stand-off antitank weapons.[2] But the existing US air defense gun system, the M-163 Vulcan, was inadequate to meet the enhanced threat. The Vulcan's maximum range was 2 km whereas Soviet helicopters carried antitank weapons that could be launched from a stand-off range of 2-4 km.[3] The Vulcan's 20mm Gatling gun was insufficiently lethal, especially against armored Soviet helicopters. The Vulcan had inadequate accuracy because it utilized only optical sensors for target acquisition and tracking and because the long flight time of its projectile enabled targets

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4839.

[2] In addition, the Soviets had deployed the advanced ZSU-23 air defense gun system.

[3] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 803. In addition, the new generation Soviet AT-6 Spiral antitank missile would have a range of 5 km, as reported in J. Philip Geddes, "The U.S. Army's Division Air Defense System," page 883.

to escape through evasive maneuvers. Further, the Vulcan's optical sensors and manual fire control were inadequate under adverse weather conditions and for quick reaction to terrain-following aircraft or "pop-up" helicopters. The Vulcan was not survivable in the forward battle area, being mounted on a lightly armored M-113 armored personnel carrier with an open gun turret. Finally, the M-113 did not provide mobility comparable to that of the maneuver elements to be protected.

Also, while air defense had come to depend primarily on missiles, the existing missile systems were not well-suited to meet the low-altitude threat in the forward battle area. The Hawk, Nike Hercules, and (soon the) Patriot missiles provided medium and high-altitude defense, encouraging the Soviets to employ low-altitude approaches. The Chaparral missile system provided short-range defense but was not armored and could not "shoot-on-the-move" and thus was inadequate for use in the forward battle area. The Redeye and Stinger were shoulder-fired heat-seeking missiles but relied on optical target acquisition.

The Sgt. York was thus developed to meet a need not satisfied by the Vulcan or existing missile systems. A medium-caliber, 40mm gun system is employed in order to increase lethality and extend the maximum range to approximately 4 km.[1] The system utilizes twin guns in order to improve accuracy. The Sgt. York's fire control system is fully automatic in order to provide accuracy at extended ranges, quick reactions, and capability in adverse weather. The fire control system utilizes a digital computer that

[1] See J. Philip Geddes, op. cit, page 885.

depends on separate radars for surveillance and tracking.[1] The system is designed to resist radar jamming and includes an electronic system (IFF) to distinguish friendly from hostile aircraft. In automatic operation, the computer identifies and prioritizes the targets, points the gun (by directing an hydraulic system), selects the ammunition type, and computes the burst length. The gunner need only pull the trigger. As a backup to the radar system and for use when necessary to avoid detection by Soviet radar-homing missiles, the Sgt. York includes a complementary electro-optical sighting/ranging system consisting of a laser range finder, optical day sights, and a low-light sight for night vision. The Sgt. York is mounted on an M48A5 tank chassis with an armored, stabilized turret for survivability and mobility, including a shoot-on-the-move capability over rough terrain. Thus, the Sgt. York is a complex and advanced system.

2. Early Program History

The Army studied air defense guns extensively during the 1960s and early 1970s.[2] The most significant experimental precursor to the Sgt. York Program was the Gun Low-Altitude Air Defense (GLAAD) advanced development program.[3] In June 1973 Ford Aerospace and Communications Corporation (FACC) won a contract to develop and test a prototype fire control test

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[1]The system is said to be capable of detecting incoming missiles at up to 10 km. See J. Philip Geddes, op. cit., page 884.

[2]See J. Philip Geddes, op. cit., page 881, for a partial listing of these studies.

[3]This discussion of the GLAAD Program is based on Paul Carrick, "Competition as an Acquisition Strategy," unpublished paper, pages 174-176.

bed. FACC was to mount a 25mm gun on an armored personnel carrier and to evaluate the use of a digital computer to calculate gun-pointing instructions. Target information was to be acquired by optical, infrared, and laser sensors (but not through the use of radar). The GLAAD program was completed in June 1976, at a cost of over $8.5 million and provided valuable information on realistic gun system performance goals as well as validated the use of a digital computer for second-order gun fire control.

The Army also benefited from the experience of the West Germans who had developed a radar-directed, tank-mounted, 35mm antiaircraft gun system, namely the Gepard Flakpanzer. The US Army gave serious consideration to procuring the Flakpanzer in late 1976 and again in 1977.[1] As it turned out, the Sgt. York is superior in performance and more advanced than the Gepard.[2]

As indicated in Table C-1, the Army formally initiated the Sgt. York Program in August 1976, and development contracts were awarded in January 1978. The intervening period was characterized by deliberation and controversy, including an intense debate over whether a gun system (as

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[1]As late as March 1978 the Army was considering leasing the Flakpanzer in order to meet its urgent requirements. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4846.

[2]See J. Philip Ceddes, op cit., page 883. The Sgt. York has better accuracy, a shorter reaction time, and carries more ammunition.

Table C-1. CHRONOLOGY OF EARLY SGT. YORK PROGRAM EVENTS

DATE	EVENT
1969-1976	Experiments and gun component evaluations.
June 1973	GLAAD development contract awarded to FACC.
August 1976	Army approves Required Operational Capability (ROC) document.
February 1977	DSARC I establishes acquisition strategy.
April 1977	Army issues Request for Proposals (RFP) for ED based on revised ROC.
November 1977	Army selects FACC and GDP for competitive ED.
January 1978	DSARC II approves ED and awards contracts for Phase 1 to FACC and GDP.

opposed to a missile system) was even required.[1] Two DSARCs were conducted to define, revise, and finally approve an acquisition strategy. Cost and operational effectiveness studies were analyzed and the possibility of procuring a European gun system was evaluated. In the meantime, five companies submitted proposals for the Phase 1 engineering development (ED) contracts. On January 13, 1978 competitive ED contracts were awarded to Ford Aerospace and Communications Corporation (FACC) and General Dynamics-Pomona (GDP).

3. Acquisition Strategy

Acquisition strategy for the Sgt. York was shaped by the need to reduce substantially the time normally required to develop and field a major weapon system.[2] This urgency reflected both the growing Soviet air support capability and general Congressional pressure to reduce development time and costs.[3] In order to expedite the acquisition program, a substantial amount of concurrency was planned and a "hands off" approach was adopted for the system design. But in order to reduce the schedule and cost risks inherent in such a strategy, mature subsystems were required and development competition was introduced.[4]

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[1] See Armed Forces Journal International, January, 1978, page 12.

[2] In addition, DoD utilized the program to test new acquisition approaches.

[3] See, for example, Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4840. Nevertheless, the program ranked only fourth or fifth in priority among Army acquisition programs.

[4] For a discussion of the Sgt. York acquisition strategy, see Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, pages 802-812.

Concurrency was planned at several stages. First, there would not be a separate advanced development phase. Any concepts that had not already been demonstrated during earlier component tests would be validated during engineering development (ED). Further, the ED prototypes would be designed for production in order to facilitate Phase 2 concurrency of design maturation and initial system production. Thus, the Phase 1 prototypes were to incorporate all of the hardware subsystems envisioned for the final production systems.[1] Finally, the development of certain maintenance and training hardware would be deferred until Phase 2, in part to avoid the higher R&D costs of competitive development (in Phase 1).

The "hands off" approach was adopted in order to reduce development time by giving contractors freedom to make and implement design decisions quickly without government interference.[2] In addition, this method would take advantage of competitively motivated contractor ingenuity in designing a cost effective system. The contractors were required to develop systems that satisfied 12 firm performance specifications.[3] In addition, the Army identified 43 system characteristics and prioritized them using three categories, namely--features most desired, next most desired, and also desired. A design-to-cost (DTC) goal for contractor recurring

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[1]The only major omission was the software for the built-in test equipment (BITE).

[2]That is, user requirements would not change and Army engineers would not tell the contractors how to design the systems. An effort was made to specify requirements in terms of functions rather than equipments.

[3]For example, the contractors were required to use 30-40mm guns and M48A5 chassis.

hardware costs was established at approximately $1.1 million (in constant 1978 dollars) and the contractors were given complete latitude to make cost/performance trade-offs in light of the Army's priorities and to develop systems they felt best met the Army's needs.[1] Contractor reporting was minimized and consisted mainly of quarterly reports.[2] In lieu of Government controls, the ED contracts were fixed-price, best-effort contracts.

In order to reduce the schedule and cost risks associated with program concurrency and the "hands off" approach, the contractors were required to utilize mature, proven components and subsystems. This maturity requirement reduced the design issues and hence the need for a separate advanced development phase. It facilitated the development of production-ready ED prototypes and lessened the need for government surveillance of the development effort.[3]

While mature components would reduce design risks, competition was maintained through the engineering development (ED) stage in order to reduce management risks. Competition between FACC and GDP would motivate them to complete the Phase 1 ED on time and to prepare well for meeting the sole-source Phase 2 schedule. Further, competition would motivate the companies to develop cost effective systems even without

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[1]The Army's own design-to-unit-production-cost (DTUPC) goal of $1.9 million (in constant 1978 dollars) also included nonrecurring costs, GFE, and certain other cost categories.

[2]In particular, users within the Army did not interact with development contractors.

[3]The maturity strategy for the Sgt. York has been attributed to a staff member of the House Armed Services Committee. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 802.

Government supervision and hence would make the "hands off" approach feasible. Finally, the need to deliver competitive prototype systems on time would motivate the contractors to cooperate with the mature-components strategy.

4. Conduct of Competitive Development

Three phases were planned for the Sgt. York acquisition program, namely:

- A competitive Phase 1 for engineering development (ED);
- A competitively awarded, sole-source Phase 2 to complete ED and initiate production; and
- A competitively awarded, sole-source Phase 3 to complete procurement.

Fixed-price, best-effort contracts for Phase 1 were awarded to FACC and GDP in January 1978, for $39.6 million and $39.1 million respectively.[1] The contractors were to conduct 29-month engineering development (ED) programs including design, fabrication, and component integration for two (each) prototype gun systems. Phase 1 called for only limited design of maintenance and training hardware and logistics planning. The emphasis during Phase 1 was to be placed on the design of the fire control subsystem and on the integration of components into the complete gun system. Phase 1 was to end with selection of a single contractor for Phase 2, based on competitive proposals submitted by FACC and GDP and on the results of a three-month test (i.e., shoot-off) of the prototype systems to be conducted by the Army. The winner

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[1] See Selected Acquisition Report (U), December 1980. SECRET. Information derived for this report is Unclassified.

would be awarded a fixed-price-incentive (FPI) contract to complete ED, with FPI options for production buys through FY84.

As noted above, the ED program was to be a "hands off" effort, and this did indeed occur. The contractors briefed the Army's Sgt. York Project Management Office (PMO) quarterly to report on how they were implementing their designs and on their cost/performance trade-offs but they did not receive feedback on correcting problems and any PMO comments that they elicited were to be used at their own discretion.[1] The PMO did not present midstream changes in requirements[2] and rigidly restricted access to the contractors by all Government personnel. The "hands off" approach is credited with a 50-percent reduction from the normally required PMO staff level as well as personnel savings at the contractors.[3]

The original plan called for the developed prototype gun systems to be delivered to Ft. Bliss, Texas for a three-month, integrated development and operational test (DT/OT) program. The contractors would have the option of conducting up to two months of tests at Ft. Bliss to resolve problems and then would be required to conduct one-month demonstrations of safety and essential system performance requirements. In June 1980, the prototypes were to be turned over to the Army for the DT/OT.

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4841.

[2]The Army was able to avoid major requirements changes, which might have given a competitive advantage to one or the other of the contractors.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 1, 1977, Page 4073.

As it turned out, the GDP prototypes were not deliverd to Ft. Bliss until May and the FACC prototypes arrived in June. Due to the late deliveries and the unexpected immaturity of the prototypes, the contractor demonstration tests were cancelled and the DT/OT program was delayed.[1] Further, the DT/OT program was extended from three to five months, in part, to permit intermittent changes to the prototypes.[2] In the end, the Army was able to cover all of its planned test areas, but was forced to cut back on some planned tests.

The planned DT/OT program was extensive and was designed to test the working of the integrated systems.[3] There were to be over 900 engagements per contractor including 552 aerial passes, 156 for live fire, and 110 in an electronic countermeasures (ECM) environment. Targets would include sub-scale drones and full-size helicopters and fixed-wing aircraft as well as ground targets. The fire control systems would operate for 200 hours and 900 ammunition rounds would be expended. The tests would include three separate 72-hour periods of uninterrupted operation to check reliability and maintainability characteristics.

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[1]See Comptroller General of the United States, "Tests and Evaluations Still in Progress Should Indicate Division Air Defense Gun's Potential Effectiveness" (U), pages 5, 12. SECRET. Information derived for this report is Unclassified.

[2]Additional funding of spare parts for the prototypes might have reduced delays during the test program. It is not clear whether additional R&D funding would have improved the initial readiness of the prototypes. Based on discussions at the PMC.

[3]See J. Philip Geddes, op. cit., pages 879,885 and Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, pages 806-807.

While the contractors were permitted to observe the tests and were given the raw test data for their own prototypes, they were not given feedback or access to Army assessments. They were allowed to implement certain design fixes and software changes during the course of the shoot-off but neither contractor made modifications based on observing the performance of the other's system.[1]

C. COMPETITIVE INCENTIVES TO CONTROL COST

Was the competition structured in such a way as to motivate FACC and GDP to control and reduce eventual procurement costs? This section addresses that question and examines the incentives that were built into the competitive program. Section D will examine the results of the competition and ask whether the competition did in fact lead to lower procurement costs.

1. Value of Winning

How badly did FACC and GDP want to win the competition? Certainly the prize was substantial. Total program costs are estimated at $4.2 billion in inflation-escalated dollars.[2] The winner of the Phase 1 competition would receive options to produce 276 systems in FY82, 83, and 84 and would have a substantial advantage in any follow-on competition for producing the remaining 342 systems. In addition, there would be good potential for foreign military sales (FMS). For

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[1]Based on Paul Carrick, "Competition as an Acquisition Strategy," unpublished paper, page 222.

[2]See Office of the Secretary of Defense, Selected Acquisition Report (U), September 1982. SECRET. Information derived for this report is Unclassified.

example, both Canada and the UK are currently considering major low-level air defense acquisitions. The Army's project manager for the Sgt. York reported that the:

> contractors are highly motivated by the competitive acquisition strategy, and the Army has a high expectation of obtaining an affordable, cost effective system which can be supported in the field."[1]

Further, the contractors assigned their best personnel and considerable top management attention to the project.[2] Due to the intensity of the competition and the fixed-price nature of the R&D contracts, both firms expended a substantial amount of company funds.[3]

2. Credibility of Competitors

Did the contractors take each other's chances of winning seriously (so that they would have to try hard themselves)? There are several good reasons to believe so. First, both contractors had relevant prior experience. By the early 1970s, GDP had developed the radar-directed, Phalanx Air Defense Gun System for the Navy and hence possessed both experience and relevant specialized facilities. In June 1973,

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[1] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5. 1980, page 813.

[2] FACC, for example, considered the program to be a major product diversification requiring a "must win" effort.

[3] PMO officials estimated that each competitor contributed $10-15 million of company funds during Phase 1. Ford noted that the costs of preparing the Phase 2 proposal (not reimburseable under the Phase 1 contract) may have amounted to $8 million. And in Paul Carrick, "Competition as an Acquisition Strategy," page 192, 196, GDP reported spending $1 million just for spares to support the DT/OT program and $500,000 per month to keep its project team intact afterwards.

FACC had been awarded the GLAAD development contract (for which GDP was a principal competitor) and had successfully validated air defense fire control utilizing a digital computer. In addition, the program emphasis on mature components would allow both FACC and GDP to draw on the proven experience of major subcontractors. By reducing technical risks, the maturity strategy would thus improve the chances that both competitors could develop credible systems.[1]

Further, the "hands off" ED program was structured so that the competitors would receive virtually no information on each other's progress.[2] Thus, even if one contractor's system were clearly inferior, the other contractor could be expected to remain strongly motivated. During the DT/OT (i.e., the shoot-off), the Army provided each contractor with the raw test data for only its own system. But the competitors were allowed to view each other's test firings, and so each would have known that its opponent had defeated over twelve aerial targets and hence had to be taken seriously.[3] Further, since the contractors were permitted to amend their proposed designs after the DT/OT to include (untested) fixes for problems encountered during the DT/OT, even detailed knowledge of an opponent's test deficiencies would not have been conclusive. Thus, there was ample reason for FACC and GDP to take each other seriously throughout the competition and including the

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[1]Nevertheless, the development program would present a challenge, owing to demanding performance requirements and the accelerated schedule.

[2]At least the PMO did not serve as a conduit for such information. What the contractors may have learned through other means is not known.

[3]See Office of the Secretary of Defense, Selected Acquisition Report (U), December 1980. SECRET. Information derived for this report is Unclassified.

time (i.e., April 1981) at which they submitted their best-and-final-offer (BAFO) cost proposals.[1]

3. Importance of Cost among Program Objectives

Was the control and reduction of eventual procurement costs likely to help a contractor win the competition? In 1982, the project manager (PM) reflected on the Sgt. York's cost history and noted:

> ...I feel my No.1 priority is cost control....[2]

More specifically, the RFP for Phase 2 described the criteria that would be used to evaluate the proposals submitted by FACC and GDP.[3] The seven major evaluation factors were to be:

System Performance
Cost
Producibility
Supportability
Tactical Suitability
Management
NATO Interoperability.

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[1]FACC officials indicate that they jealously guarded information on their own final cost position. In order to avoid any possibility of a leak to GDP, FACC hand-delivered its BAFO to the Army at the last possible minute.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 814.

[3]See US Army Armament Research and Development Command, Request for Proposal DAAK-10-80-R-0027, Section D.

System performance and cost were the most important criteria and carried equal weight.[1] The cost factor considered the following subfactors listed in order of importance:

Investment Cost
Research and Development
Operating and Support.

Investment cost included production and related costs and special emphasis was to be placed on correlation with the offeror's Phase 1 Design-to-Unit Production-Cost (DTUPC) goal. Cost/performance trade-offs made during Phase 1 would be evaluated in light of the above criteria. And greater score would be given for the use of mature components.

In addition to the incentive to control unit costs that the competition provided, the contractors may also have been motivated by the need to protect the DIVAD[2] Program from cancellation. The DIVAD presented an obvious target for DoD and Congressional budget cutters since it was an expensive system but was ranked only fourth or fifth in priority among the Army's acquisition programs. Before Phase 1 even began it was extended from 24 to 29 months due to funding problems, and the source selection for Phase 2 was similarly delayed for six months due to budgetary limitations. The DIVAD Program was also on shaky ground due to substantial controversy between gun and missile advocates for air defense. Accordingly, the contractors may have recognized a need to design systems that

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[1]Discussions with PMO officials indicate that both contractors in fact believed that cost and performance would carry approximately equal weight in the source selection.

[2]During R&D, the Sgt. York was known as the Division Air Defense Gun System (DIVAD).

the Army could afford and that would not risk program cancellation.[1]

4. Validation of Cost Estimates

Was the Government able to validate contractor estimates of eventual procurement costs? This would improve the Government's ability to predict what would happen to prices in Phase 3, when the competitively negotiated production options would no longer be applicable. Thus, good cost validation would reduce the contractors' incentive to buy in during Phase 2.

The Sgt. York Program possessed both advantages and disadvantages for cost validation. On the positive side, mature components accounted for some 70 percent of total system costs.[2] Since most of these components were already in production, uncertainties affecting production costs such as transition design changes and the shape of the learning curve were greatly reduced. Further, the ED test vehicles were "prototyped for production."[3] That is, a high proportion of the new items were also in production configuration (e.g., production castings were used in some cases rather than the

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[1]Discussions with FACC officials indicate that FACC pays close attention to what funding the Army will have available for a procurement program and, further, carefully assesses a program's chances of cancellation or reduction before it decides to participate. In the case of DIVAD, these considerations reinforced the importance FACC placed on achieving the DTUPC goal.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1981, pages 808-810.

[3]Ibid., p. 809.

usual R&D hang-outs) and production processes and facilities were planned.[1]

On the other hand, the "hands off" development strategy may have limited the Government's efforts to validate production cost estimates.[2] While complete bottoms-up cost estimates were developed by the Army for the source selection process, design-to-cost (DTC) reviews (comparable in detail to other programs) were not conducted during Phase 1. In addition, the design and fabrication of much important support equipment was deferred until Phase 2 so that there was no hardware basis for validating production cost estimates for them by the end of the competition. This included training equipment as well as expensive and sophisticated field maintenance test sets.[3]

5. **Priced Production Options**

The contractors were required to include production options with firm ceiling prices in their Phase 2 proposals. Ceiling prices were required for the fire units themselves as well as for the ammunition and spares and repair parts necessary to support the option fire units. Ceiling prices

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[1] Discussions at FACC indicate that manufacturing specialists were involved from the beginning of the development. The need to propose firm ceiling prices mandated that FACC know its expected production costs.

[2] In Comptroller General of the United States, "Tests and Evaluations Still in Progress Should Indicate Division Air Defense Gun's Potential Effectiveness" (U), page iii, SECRET, it is suggested that the "hands off" approach, by reducing the flow of development information, may have limited the Government's ability to evaluate the Sgt. York. (Information derived for this report is Unclassified).

[3] While the Phase 1 contracts did not fund prototypes for these items, the contractors did sufficient work on their own to permit them to propose prudent ceiling prices.

were also required for the Phase 2 R&D effort and for the Government's investment in special tools and special test equipment to support production. The proposals envisioned an initial contract for continued development and preparation for production in FY81 plus options to produce 50 complete fire units in FY82, 96 in FY83, and 130 in FY84. Thus, the options covered a substantial portion (i.e., 45 percent) of the total planned buy of 618 fire units. This would make it particularly costly for one of the competitors to buy in rather than lower costs. In addition, production cost experience for the first 90-100 fire units would be known by the time negotiations started for the follow-on Phase 3 production contract in January-February 1985. Thus, contractor efforts to control costs under the competitively negotiated ceilings would aid the Army in negotiating a favorable Phase 3 contract even under sole-source conditions.[1]

The RFP required the contractors to propose fixed-price incentive contracts with firm targets (FPIF).[2] Profit was to be ten percent of target cost and the firm ceiling price would vary from 135 percent of target costs for FY81 to 125 percent

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[1]That is, the Army could be expected to insist that the Phase 3 learning curve be consistent with the curve demonstrated during Phase 2.

[2]See US Army Armament Research and Development Command, Request for Proposal DAAK10-80-R-0027, 1980, Section D.

for the FY84 option.[1] The Government's share of costs in excess of target costs would vary from 90 percent (up to the ceiling price) in FY81 to 80 percent for the FY84 option. The contract would include a price escalator for inflation and an additional award fee for demonstrated growth in reliability and maintainability. The production options had to be exercised by specified dates but the production quantities could be varied by ± ten percent without affecting the ceiling prices. The best and final offer (BAFO) proposals were submitted by the contractors in April 1981, five months following completion of the DT/OT.

6. Competition during Follow-On Procurement

Did the contractors anticipate competition for procurement contracts after the competitively negotiated Phase 2 options were no longer applicable? If they did, then their incentive to buy in would have been reduced since they could not expect to recoup Phase 2 losses during Phase 3. Thus,

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[1]An initial ceiling of 135 percent of target cost (or 123 percent of target price) appears to be generous but may have been necessary to induce the contractors to propose FPI (rather than the usual CPIF) contracts for the Phase 2 R&D effort and to propose firm ceiling prices for production options before development was completed. An FPI contract for the R&D effort was particularly important since the Phase 2 contractor would have an incentive to increase R&D costs in an attempt to reduce production costs below its firm production option prices. In light of the competitive bidding for the Phase 2 contract, it is not clear that the stated percentages (specified by the Army) affected the proposed ceiling prices for the production options.

they would have felt greater pressure to reduce costs in order to hold down their Phase 2 price proposals.[1]

The RFP for Phase 2 required FACC and GDP to propose delivery of complete level-three technical data packages (TDPs) suitable for competitive procurement.[2] FACC's TDP is now due in October 1984, and would thus be available six months before the first Phase 3 buy in FY85. In March of 1978, the Army reported that the Phase 3 "... systems are presently planned to be competitively procured."[3] In 1980, the Army reported plans to initiate competitive procurement of ammunition (and to begin procuring it separately from the fire units) in FY85.[4] At the time of the source selection for Phase 2 it was reported that the Army might seek a competitive buy-out (with annual options) for the 342 Phase 3 fire units.[5]

But while the possibility of competing the Phase 3 awards existed (and is still being evaluated), the contractors had some reason to be skeptical about this threat. Since 45 percent of the fire units would be built during Phase 2, relatively few units would remain over which to spread the

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[1]On the other hand, the possibility that the Phase 2 contractor might not receive the Phase 3 award could tend to increase the Phase 2 proposals since the Phase 2 contractor would expect to have fewer units over which to amortize its own start-up costs and cost-reducing investments.

[2]See US Army Armament Research and Development Command, Request for Proposal DAAK10-80-R-0027, Attachment II.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4841.

[4]Ibid., p. 719.

[5]See J. Philip Geddes, op. cit., page 887.

start-up costs of a new producer.[1] Turning to a new producer would also risk delaying deliveries of an urgently needed weapon.

7. Correction of Design Deficiencies

In their Phase 2 proposals, the contractors were required to accept total system responsibility. Under this concept, the contractors were to specify the performance and reliability and maintainability levels that their systems would achieve and were to agree to correct any failures to meet those specifications at their own expense.[2] The winning contractor would be responsible for correcting any failure to meet those specifications due to defective design for six months after Army acceptance of the first unit (and was responsible for correcting failures due to defective workmanship or materials for six months after Army acceptance of each unit).[3] Design corrections applied to newly produced units would be applied to previously produced units as well. There would be no change in target cost, target profit, or the price ceiling as a result of corrections made under this provision. The contractor would retain control over system configuration until the initial production test and completion of the TDP.

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[1] Discussions at the PMO suggest start-up costs might now be as high as $75 million.

[2] The proposals did not include specific line items to indicate the target costs for this responsibility but it can be presumed that the overall proposal reflected such costs.

[3] See US Army Armament Research and Development Command, Request for Proposal DAAK10-80-R-0027, 1980, Section J.36.

The total system responsibility provision could be expected to control procurement costs by (in effect) placing a ceiling on the cost of design corrections to meet the system specifications. In addition, it would motivate the contractors to propose realistic specifications (while the competition provided an incentive to propose demanding specifications).[1]

8. Summary of Competitive Incentives

Considering the structure of the competitive program, FACC and GDP should have been strongly motivated to control and reduce expected production costs. Cost promised to play a very important role during source selection due to its equal ranking with performance at the top of the prospective evaluation factors and also because the experience of the contractors and the emphasis on mature components made both FACC and GDP credible competitors as regards system performance and other non-cost factors. Further, since the contractors were required to include firm-price options for Phase 2 production (amounting to 45 percent of the total planned buy) in their competitive proposals and since a TDP was required in time to permit (if desired) a competition for the follow-on Phase 3 production contract, the contractors would be under great pressure to control and reduce expected production costs. Subsystems were completely integrated in the Phase 1 prototypes, and the comprehensive ceiling prices included the fire units, ammunition, initial spares, support

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[1] The provision was not included in the original Phase 1 RFP and thus should not have affected the Phase 1 design effort. But it could be expected to motivate the winning contractor (to control the costs and adverse performance impacts of future design changes) during the Phase 2 design maturation effort.

hardware, and Government facilitization costs. The first production option was to be exercised within a year of the beginning of Phase 2. Finally, the requirement that the winning contractor assume total responsibility for meeting the performance and reliability specifications it proposed would motivate the contractors to maintain quality in their development effort and realism in their production planning and competitive proposals.

D. RESULTS OF COMPETITIVE ED

1. Source Selection

The original plan was for a three-month DT/OT ending in August 1980, followed immediately by selection of a winning contractor for Phase 2. Instead, the source selection was not made until May 7, 1981, as indicated on Table C-2. In part, the delay was due to a two-month extension of the DT/OT owing to the unexpected immaturity of the prototypes.[1] The additional six-month delay resulted largely from budgetary problems. The DT/OT coincided with preparation of the FY82 budget request and with severe fiscal pressure on the Army.[2] According to the Army, it:

> appeared that the (Sgt. York) gun program might not be able to be funded, so we paused in our prosecution of that program because of the uncertainty.[3]

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[1]See Section B above.

[2]See Aviation Week and Space Technology, November 10, 1980, page 37.

[3]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 16, 1981, page 161.

Table C-2. CHRONOLOGY OF LATER SGT. YORK PROGRAM EVENTS

DATE	EVENT
January 1978	FACC and GDP Initiate Competitive ED.
June 1980	DT/OT (i.e, shoot-off) begins.
November 1980	DT/OT completed.
April 1981	Best and final offers (BAFOs) received.
May 1981	FACC selected for Phase 2 contract.
January 1982	Maturation check tests completed.
May 1982	DSARC III approves production, FY82 production option exercised.
September 1983	Delivery of first production unit.
October 1984	Expect completion of technical data package (TDP).
March 1985	Expect initial operational capability (IOC).
April 1985	Expect award of Phase 3 production contract.
FY87	Expect exercise of final production option.

As a result of the fiscal pressure, the FY81 procurement request was reduced by $129.1 million, eliminating a planned initial buy of 12 fire units in FY81 and delaying initial fielding by six months.[1] The ED contracts for FACC and GDP were increased by $3.8 million and $3.7 million (respectively):

> due to 60-day extension of DT/OT and interim contracts to maintain contractor team continuity and begin system maturity effort prior to source selection and contract award.[2]

The Phase 2 contract awarded to FACC provided for design maturation and production preparation for FY81 with separate production options for 50, 96, and 130 fire units in FY82, FY83, and FY84 (respectively). The initial FY 81 contract would require:

- a maturity phase to correct DT/OT deficiencies;
- development of trainers and peculiar support equipment, logistics planning, and a complete technical data package (TDP);
- foreign technology transfer, fabrication and testing;
- final producibility engineering and planning; and
- procurement of long-lead items and initial production facilitization to support the FY82 production option.[3]

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 805.

[2]See Selected Acquisition Report (U), December 1980. SECRET. Nevertheless, FACC was forced to reduce its program personnel from 300 to 50 during the six-month delay. (Information derived for this report is Unclassified.

[3]See US Army Armament Research and Development Command, Request for Proposal DAAK10-80-R-0027, 1980, Section A.

The six-month maturation phase would be followed by a three-month check test to verify correction of the DT/OT deficiencies.

No official document was published to explain why FACC was selected, but FACC did achieve its design-to-cost (DTC) goal and still met 41 out of the 43 tradeable design characteristics.[1] Both contractors satisfied the 12 mandatory requirements.

As noted above, each contractor defeated over 12 aerial targets during the DT/OT. It was also reported that the FACC entries shot down every full-sized aerial target presented.[2] Evidently, FACC did far worse than GDP in terms of direct hits against aerial targets, but the results were approximately even when indirect hits (by PX rounds detonating in the vicinity of a target) were considered.[3] The effectiveness of the PX round was controversial, and FACC's claims were not accepted until a report by the Army's Ballistics Research Laboratory (BRL) following the DT/OT.[4]

The DT/OT revealed design problems with the prototypes of both contractors. Such problems were to be expected and a maturity period of six to eight months for the winner to

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[1] Discussions with FACC officials further indicate that FACC had originally expected system performance and procurement costs to be about equal between the FACC and GDP designs and had chosen to emphasize control of operating and support costs as a potential discriminator in the source selection.

[2] See J. Philip Geddes, op. cit., page 885.

[3] See Gregg Easterbrook, "DIVAD," The Atlantic Monthly, October, 1982, page 35.

[4] Based on Paul Carrick, "Competition as an Acquisition Strategy," page 209.

correct design problems had been planned prior to the DT/OT. FACC was judged to have 29 deficiencies (i.e., failures to meet minimum requirements) and 12 shortcomings (i.e., other undesirable characteristics). The major FACC deficiencies included problems with:

- system reaction time,
- software integration, especially that affecting IFF performance,
- turret armor protection,
- excess weight (61.5 vs 60 tons),
- radar peformance in ECM environment,
- PX-round effectiveness in countermeasures environment,
- gun-pointing accuracy,
- low muzzle velocity, and
- threat priority software.[1]

The major GDP deficiencies included problems with:

- system reaction time,
- reload time,
- armament feed system reliability,
- target acquisition range,
- radar/optical systems integration,
- PX round effectiveness in countermeasures environment, and
- night vision capability.[2]

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[1]Based on Comptroller General of the United States, "Tests and Evaluations Still in Progress Should Indicate Division Air Defense Gun's Potential Effectiveness" (U), page ii, 5, 6. SECRET.(Information derived for this report is Unclassified).

[2]Based on Paul Carrick, op. cit., page 203.

Of course, the contractors included design modifications in their Phase 2 proposals to correct their deficiencies. For example, after the DT/OT GDP redesigned its gun feed system and reworked its fire control software to reduce system reaction time.[1] FACC also had software problems to correct. And FACC proposed to redesign its turret during Phase 2 in order to reduce its weight.[2]

2. Use of Mature Components

As discussed above, a major element of the Sgt. York acquisition strategy was that substantial use be made of mature components that had been developed for other programs and that were ready for production. Mature components would reduce the risks associated with an expedited schedule and the "hands off" approach.[3] Further, by using mature components, the Sgt. York program could be expected to reduce procurement costs by:

- avoiding procurement cost risks associated with developing new components (and reduce R&D costs);[4]
- avoiding learning and other production start-up costs; and

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[1]Based on Paul Carrick, op. cit., page 217.

[2]Discussions at FACC indicate FACC also expected the redesign to reduce unit costs but the material savings proved to be offset by higher manufacturing costs.

[3]Discussions with PMO officials suggest that the mature-components strategy proved to be a major factor in the program's success.

[4]For example, mature components gave the contractors more confidence in their cost estimates when preparing their Phase 2 bids.

- taking advantage of production economies of scale.[1]

Was competition partially responsible for the substantial use that was actually made of mature components? The Sgt. York program manager made the following observation:

> Although the government requested use of mature major components it was competition and the management of risk that drove each to select not only the components but the experienced production subcontractors as team members to assure readiness with confidence.[2]

The contractors were driven to cooperate with the Government's maturity strategy because the expedited schedule denied the time and the fixed-price ED contracts denied the funding necessary to develop new major components at an acceptable level of risk. But it was competition that did the driving.[3] That is, it was competition that compelled FACC and GDP to do what was necessary to have adequate prototypes ready in time for the DT/OT and to do it for a fixed price. And it was competition that pressured them to avoid the start-up

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[1]The quantities required for the Sgt. York were too small to have much impact on the scale economies achieved in the production of preexisting components. But for the same reason, production of newly developed components solely for the Sgt. York would have resulted in a loss of scale economies.

[2]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 810.

[3]Of course, credit must also be given to the strong preference for mature components indicated in the Army's RFP. See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4079 for a discussion of the gun maturity restrictions.

costs associated with introducing newly developed components into production.[1]

In 1980, mature components were expected to account for 70 percent of the total Sgt. York system cost.[2] As indicated by Figure C-1, the turret/drive was the only major subsystem not expected to embody primarily mature components. Table C-3 summarizes the sources and maturity status of several major items.

Government-furnished equipment (GFE) for the Sgt. York was overwhelmingly mature. GFE included the tank chassis on which the gun turret was mounted. This was an M48A1/M48A2 chassis upgraded with a new engine and transmission to be automotively comparable to the M48A5, at a cost of $250,000 per tank.[3] The M48 was selected by the Army in January 1977, and plans called for 650 tanks to be converted at the Army's Anniston depot as they became available. Another GFE item, the Identification Friend or Foe (IFF) system, was developed from the IFF used for the Stinger missile with 90 percent

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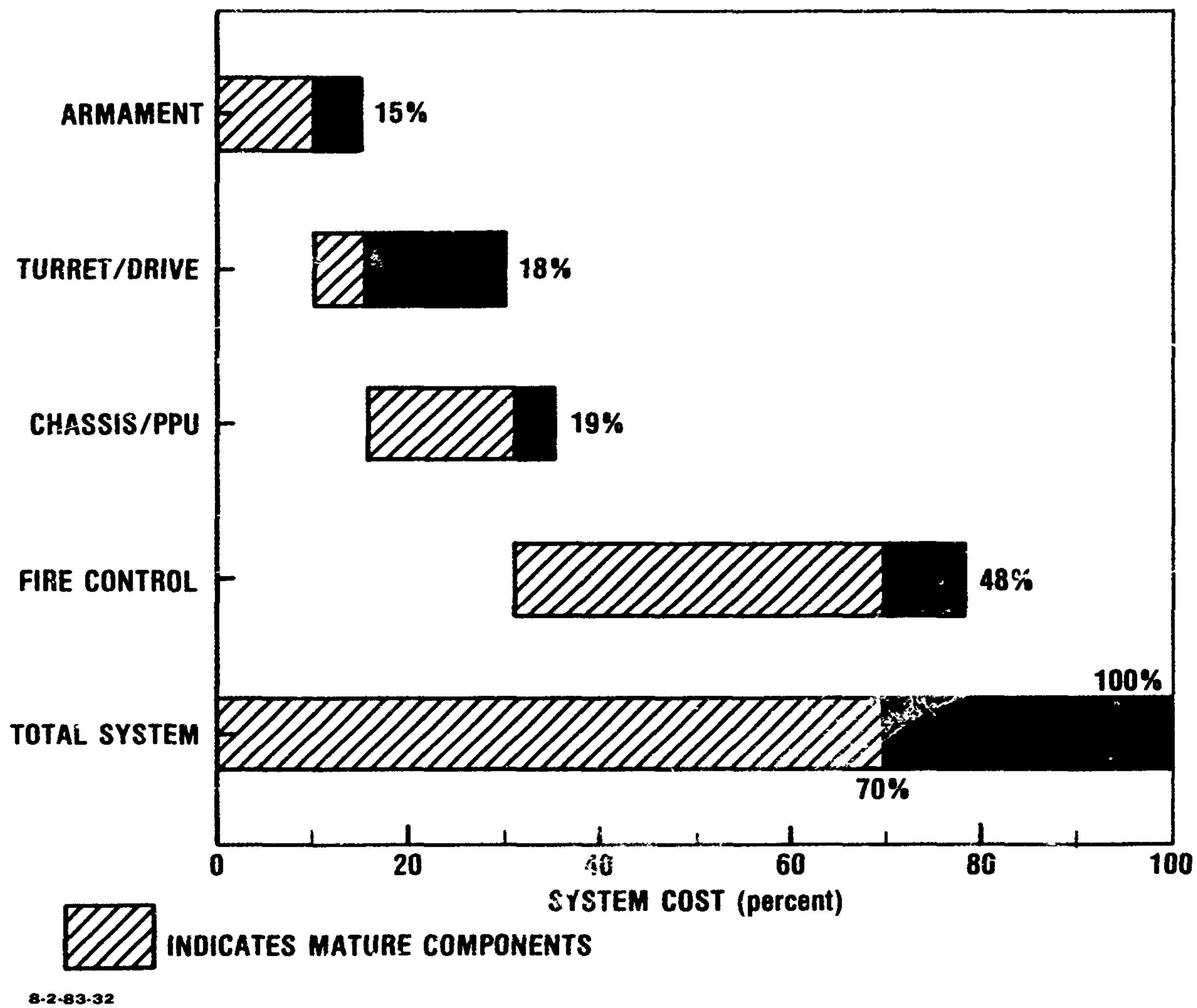
[1]Discussions at the PMO suggest that in a more leisurely, sole-source environment a prime contractor might have been motivated to develop more new subsystems in order to build up in-house state-of-the-art capabilities or to achieve greater technical performance for the gun system. It would have been very difficult and costly for the PMO to build up its capabilities in order to specify the particular areas where mature components should be used.

[2]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 809.

[3]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1979 Authorization, Part 6, March 15, 1978, page 4846.



Source: Based on figure prepared by Sgt. York Project Management Office and presented to the House Armed Services Committee, March 5, 1980.

Figure C-[illegible]. MATURITY OF COMPONENTS (AS A PERCENT OF TOTAL SYSTEM COST)

Table C-3. MATURITY OF COMPONENTS

SUBSYSTEM	FACC SOURCE	GDP SOURCE	STATUS
Chassis	M48A5	M48A5	Active Army Inventory
Communications	VRC-47	VRC-47	Active Army Inventory
Radar/Fire Control	F-16	Phalanx	In Production
Guns and Ammunition	Bofors L70 (Sweden)	Oerlikon KDA (Switzerland)	Fielded, Active Production Line in Europe
Optics	Pave Tack	Land Scout Vehicle	Extensive Prior Development
Control and Stabilization	Gun Low-Altitude Air Defense (GLAAD)	XM-1 Tank (GM)	Extensive Prior Development and Technology Base

Source: Based on table prepared by Sgt. York Project Management Office and presented to the House Armed Services Committee, March 5, 1980.

component commonality.[1] Other GFE items included the (fielded) AN/VRC47 communications set, the machine gun, and the NBC equipment.

Other mature components included the laser range finder adapted by Hughes Aircraft from the Chaparrall's range finder, the combat information display, and the Litton inertial navigation system. Many mature components had to be repackaged or modified in light of DIVAD's configuration and environment.

The DIVAD radar had to provide adequate fire control range but excessive power would produce a greater signature and hence lessen survivability. Further, the development of new radars (especially the high-frequency microwave parts) is a difficult process and would take too long for the DIVAD Program. And so the choice of radars was limited to three or four mature systems of about the right size.[2] For its radar/fire control system, GDP utilized a derivative of the system it had developed for the Navy's MK 15 Phalanx Gun System. The derivative would have 80-percent parts commonality with the Phalanx system, which achieved its IOC in August 1979.[3] FACC chose to utilize a modified version of the APG-66 radar/fire control system developed by Westinghouse for the F-16. In addition to designing new antennas, Westinghouse repackaged its radar and redesigned some of the hardware, in part, because the shock and vibration of DIVAD's ground

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[1]See J. Philip Geddes, op. cit., page 884.

[2]Phased-array radars would have had certain advantages but their reliance on solid-state emitters rather than the standard mechanical emitters brought their survivability into question and none of the five competitors for the Phase 1 contracts proposed phased-array.

[3]See Aviation Week and Space Technology, June 27, 1977, page 44.

environment was much more severe than that of the F-16's environment. Substantial commonality (with the F-16 radar) was preserved at the circuit board level, albeit less than the 70 percent that had been expected. Westinghouse's effort to achieve its demanding DTC goal was particularly important since the radar represented over 25 percent of system costs.

The armament chosen by the competitors was also mature. GDP utilized the Swiss Oerlikon KDA 35-mm gun that was in production for the new German Flakpanzer. The KDA could utilize the same ammunition as the 4000 Oerlikon KDBs that had already been fielded in Europe and elsewhere.[1] FACC chose to use the Swedish L70 40-mm gun developed by Bofors in the mid-1970s. Over 4500 L70s had been produced.[2] The L70 was modified somewhat by Bofors to accommodate the new ammunition feed system developed by FACC.[3] While the basic 40-mm ammunition was mature, some important modifications were made and are discussed below.

3. Design-to-Cost Effort

With the DIVAD, the Army made a serious attempt to encourage a design-to-cost (DTC) effort by the development contractors and current estimates indicate that the DTC goal was in fact achieved. To a large extent, requirements were defined in terms of functions to be performed rather than equipment to be installed and the contractors were given flexibility to determine how (and whether) to satisfy most

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 1, 1977, page 4076.

[2]See J. Philip Geddes, op. cit., page 884.

[3]See J. Philip Geddes, op. cit., page 882.

requirements while still meeting their DTC goals. To an unusual degree, the contractors were isolated from the how-to advice of Army engineers and user groups. There were no major changes in system requirements after the Phase 1 RFP. The DIVAD project manager later observed:

> The other thing I think we can be proud of is the requirements area from the user, that has not changed one bit since 1977. There has not been one change to the requirement, and the Army's position is to resist vigorously any changes to their system.[1]

The Army user groups participated in defining the DIVAD's requirements and in the source selection process (chairing the committees on tactical suitability and supportability). But the structure of the Phase 1 competition prevented them from directly influencing the contractors during the Phase 1 development effort. The PMO strictly controlled access to the contractors by all Government personnel.[2]

The competitors attempted to provide the Army with as many capabilities as possible without exceeding their DTC goals, and implemented a number of cost-saving ideas.[3] System performance actually exceeded Army expectations in a number of areas such as gun accuracy and lethality, electronic

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Fiscal Year 1983, Part 3, March 18, 1982, page 815.

[2]The ceiling prices and total system responsibility in the Phase 2 contract provided a continuing discipline after the competitive phase since major requirements changes would have risked invalidating the production options and competitively negotiated benefits.

[3]Based on discussions at the PMO.

countermeasures and fire-on-the-move capabilities, and the number of stowed engagements.[1]

Satisfying the night vision requirement provides an example of a major cost/performance trade-off. As one of the tradeable requirements, the Army asked the contractors to consider an optical night vision device if cost effective. An expensive forward-looking infrared (FLIR) system was considered, but instead a low-light image intensifier was selected at a recurring unit cost savings currently estimated at $250-300 thousand per fire unit.[2] While the FLIR senses heat, the low-light sight requires some ambient lighting (e.g., quarter-moon visibility). FACC estimated that the FLIR would provide visibility only five to six percent more of the time than would the daylight optics and the low-light night sight, considering likely environmental conditions. Since the radar already provided a primary all-weather capability and since the additional cost would have broached the DTC goal, FACC did not propose a FLIR.

Radar power source redundancy provides another trade-off example. The radar requires steady 400 a/c power. This is provided primarily by a turbine auxiliary power unit (APU). The main tank engine provides a backup power source when the DIVAD is stationary, but the APU is preferred due to its lower fuel consumption and heat signature. Since the main engine RPM varies when the tank moves, an additional interface device would be needed in order to use the engine as a dynamic back-up radar power source. FACC saved $20-30 thousand per fire

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[1]As another example, FACC added a squad leader's periscope.

[2]Based on discussions at PMO and at FACC.

unit by not installing the interface device even though the RFP could have been interpreted as requiring it.

Another major cost savings was achieved by providing less nuclear survivability than the Army initially requested. The RFP specified that the DIVAD have the same nuclear survivability as its associated force. This was later clarified to mean surviving the same environment as had been specified for the M-1 Tank. But considering the DIVAD's radar antennas and more extensive electronics suite, it was more difficult to harden than the M-1. By foregoing some degree of nuclear survivability, a savings of approximately $100 thousand per fire unit was achieved.[1]

Further, the Army's tradeable requirements specified a closed-loop fire control system. GDP proposed such a system while FACC did not. A closed-loop system would track DIVAD's projectiles as well as the target, determine the miss distance, and re-aim the gun accordingly. GDP had developed a closed-loop system for the Phalanx Gun System it developed for the Navy (and GDP used a modified version of the Phalanx radar for its DIVAD candidate). But the Phalanx gun has an extremely high rate of fire and is directed at close-in, non-maneuvering targets. FACC did not think a closed-loop system was effective at the greater range of the DIVAD targets. Considering the flight time of the DIVAD projectiles and DIVAD's much lower rate of fire, maneuvering targets would reduce the effectiveness of a closed-loop system. Further, FACC questioned whether fire control accuracy was sufficient to support a closed-loop system at DIVAD's range, and FACC's use of a proximity-fused round (as discussed below in Section

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[1]This is a rough estimate based on discussions at the PMO.

4) meant that the potential accuracy advantage of the closed-loop system was not needed. By avoiding a closed-loop system (from the beginning) FACC was able to utilize a less complicated radar at a savings of $10-20 thousand per fire unit.

Should cost/performance trade-offs be considered in determining the procurement cost savings attributable to competition? They clearly represent savings when the items traded off prove to be unnecessary to the performance of the Army's desired function, as in the case of closed-loop fire control. The answer is less clear in cases where trade-offs result in degradation of desired functions. The competitors were encouraged to identify for the Army those desired features that were not cost effective in light of the unit costs to achieve them, the Army's priorities, and the Army's DTC goal. If the competitors eliminated items that were not cost effective but that would have been added in a sole-source environment,[1] then those trade-offs have benefited the Army.[2]

4. Choice of Armament

Choice of armament provided an important basis for differentiation of the FACC and GDP designs. FACC selected the Bofors L70 40mm gun and ammunition while GDP utilized the Oerlikon KDA 35mm gun and ammunition. Prior to the initiation of the Sgt. York Program, the Army had conducted

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[1]In a sole-source environment, contractors might encourage additional features since their profit is ultimately based on cost. Further, without the internal discipline competitive development imposes on the Army, requirements might grow more readily.

[2]Since such trade-offs do sacrifice some performance, their net benefit would be less than the amount of costs avoided.

studies of appropriate gun calibers for a new air defense weapon. According to the Army:

> The results of the evaluation showed that these armament subsystems are about equal on a cost effectiveness basis, so the Army has decided not to specify a gun and will only band the caliber from 30 to 40 millimeter in our request for proposals to industry.[1]

And the Army further reported:

> Well, we considered, frankly, preselecting the 35-millimeter gun for the reason of NATO standardization and for the reason that it appeared to be as cost effective as the others.[2]

While both the 35 and 40mm guns were widely used by NATO countries, the 35mm was to be used on the new German Flakpanzer and selection of the 35mm gun by the US would have been preferred from the interoperability viewpoint.[3] But, the Army concluded that if the RFP for Phase 1 specified that the 35mm gun be used, then one of the excluded gun producers would file and win a protest. So,

> ...in view of that, the Army made a decison to go ahead and have a competition as wide open as we could

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[1] See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 1, 1977, page 4072.

[2] Ibid., page 4077.

[3] NATO standardization was an important issue at the time, both in general and for the air defense gun system. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 6495, Fiscal Year 1981, Part 2, March 5, 1980, page 811 for a table indicating the widespread use of both calibers among NATO countries. While both calibers were in widespread use within NATO, the proximity of German and US forces on the Central Front gave the 35mm a particular advantage.

have it with the cost benefits you get from competition.....[1]

Thus, the RFP specified that the gun caliber be between 30mm and 40mm. Accordingly, the Army retained the potential cost benefits of competition among the gun subcontractors (as well as the prime contractors) and also preserved (for the prime contractors) the flexibility to make design trade-offs between armament and fire control capabilities. The Army negotiated licensing options with Bofors and Oerlikon and thus made the 35 and 40mm guns available to any of the five Phase 1 bidders. Three firms proposed 35mm guns, GE proposed its own 30mm gun, and only FACC proposed a 40mm gun.[2]

The 35 and 40mm gun systems had offsetting advantages so that a choice between them was not obvious. The 35mm gun had a higher rate of fire and, at least initially, a higher muzzle velocity and shorter flight time for its projectiles over a given distance.[3] But while these characteristics seemingly gave the 35mm gun a higher probability of hitting a given target (i.e., P_h), the 40mm round was much larger and hence could achieve a higher probability of killing a target it hit (i.e., $P_{k/h}$). For example, the 40mm system did not require a separate armor-piercing round as did the 35mm. The acquisition costs of the two guns were approximately the same, while the 40mm gun was thought to be more durable and

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[1]See Committee on Armed Services, US Senate, Hearings on Fiscal Year 1978 Authorization, Part 6, March 1, 1977, page 4077.

[2]The 35mm size was viewed as the emerging caliber, and no 40mm guns were then in US use.

[3]The 35mm gun fired 550 rounds per minute while the 40mm fired 300.

reliable.[1] The 40mm gun weighed several hundred pounds less and included fewer high-stress parts. Its lower rate of fire particularly contributed to its greater durability and lower support costs.[2]

The Army's initial conclusion that 30 to 40mm guns were about equal in cost effectiveness assumed the use of point-detonating (PD) rounds that explode after impact. But unlike its initial four competitors, FACC proposed also to use a proximity-fused (PX) round. The PX round is detonated by its target-sensing electronic fuse as it arrives in the vicinity of its target.[3] The prefragmented, high-explosive PX round[4] thus increases P_h relative to a comparable PD round by converting near misses into indirect hits. The PX round is particularly useful at greater distances where fire control accuracy is less adequate, and thus could help the 40mm gun offset the shorter time of flight and higher rate of fire for the 35mm gun. Ultimately, the PX helped FACC to achieve a higher P_h than the Army had required.[5]

The effectiveness of the two gun systems directly affected ammunition requirements and hence acquisition costs. The Army specified a profile of targets for an assumed

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[1] Discussions at FACC suggest that FACC expected the 35 and 40mm systems to be about equal in effectiveness and acquisition cost, but FACC chose the 40mm system in order to gain an advantage over GDP in life cycle costs.

[2] See J. Philip Geddes, op. cit., page 884.

[3] The vicinity may vary from 1.8 to 6.5 meters depending on target characteristics. See J. Philip Geddes, op. cit., page 885.

[4] The 40mm PX round contains tungsten balls in its steel case for great lethality.

[5] In fact, the Army had specified a nominal value for P_h but considered that to be a tradeable item rather than a performance floor.

war, and the contractors were to design systems to defeat those targets, including the selection of ammunition types and quantities to be fired at each target. The source selection was based, in part, on the estimated cost of the ammunition reserves required to support each system and the Phase 2 production options were to include the acquisition of some portion of those reserves. Thus, the competitors were to consider the cost effectiveness of the armament system as a whole, including the required ammunition. By improving P_h, the PX round would enable FACC to defeat its targets with fewer rounds. But the associated cost savings were partially offset by the high cost of the complex PX round, particularly due to its electronic fuse.[1]

Bofors had developed a 40mm PX round in the late 1960s and was producing it by 1976.[2] It was novel, however, for a round of such small caliber to include a proximity fuse. Only recently had advances in circuit miniaturization made an appropriate fuse feasible, and no PX round had yet been developed for a gun of lesser caliber.[3] The desirability of using the PX round for a medium-caliber gun had not yet been established since information on its effectiveness was deficient and its fuse was subject to electronic countermeasures (ECM) as well as being very expensive. The

[1]In Comptroller General of the United States, "Tests and Evaluations Still in Progress Should Indicate Division Air Defense Gun's Potential Effectiveness" (U), page 7, SECRET, the average cost of FACC's PX round is said to be at least 67 percent higher than that of its PD rounds. (Information derived for this report is Unclassified).

[2]The existence of a production PX round was a major factor in FACC's selection of the Bofors gun.

[3]This discussion is based on Paul Carrick, "Competition as an Acquisition Strategy," unpublished paper, page 173 and following.

Army had studied PX rounds for the air defense gun and was willing to use them if they proved to be cost effective.[1] While FACC had proposed to use a PX round at the beginning of Phase 1, GDP decided to propose a PX round only near the end and GDP's round was much less mature than FACC's.[2]

During the course of the competition, FACC designed significant improvements to its PX round to enhance its effectiveness against maneuvering targets at long distances.[3] Muzzle velocity was increased through the use of a modern US propellant and ballistic performance was improved by means of certain material substitutions. The net effect was to reduce the projectile's flight time out to 4 kilometers by a full second, to 5.97 seconds.[4] The so-called "fast bullet" changes did not increase recurring unit costs but greatly improved long-distance accuracy and hence had a major impact on the amount of PX ammunition that would be required.[5]

The lethality of even FACC's PX round was in doubt until after the DT/OT. It was in early November 1980 that the Army's Ballistics Research Laboratory (BRL) reported that the

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[1]See Committee on Appropriations, House of Representatives, Hearings on Fiscal Year 1981 Appropriations, Part 9, page 720.

[2]Discussions at the PMO suggest that while the larger 40mm shell carries the fuse and lethal warhead better, a 35mm round is large enough. The GDP PX round had a fragmenting steel case but not the tungsten balls of FACC's.

[3]These changes were included in the Phase 2 proposal and implemented during Phase 2.

[4]See J. Philip Geddes, op. cit., page 885-886.

[5]Discussions at FACC indicate that substantially more PX rounds would be required without the changes. The changes did impact R&D costs during Phase 2.

lethal radius of the 40mm PX round was almost double what the Army had previously believed on the basis of its Caywood-Schiller simulation model.[1] FACC and Bofors had been pushing the Army to revise its lethality estimates. The BRL findings, had a major impact on the amount of ammunition FACC proposed.

FACC's dual ammunition feed system also had an important impact on ammunition costs. FACC designed a linear linkless system (based on a method previously used for its 25mm gun) that permitted ammunition to be individually selected for each of the twin guns from either of two dedicated magazines (per gun).[2] In contrast, GDP's system fed linked ammunition to its gun and hence the selection of rounds was predetermined at the time the ammunition was linked. Thus GDP was forced to intersperse its more expensive armor-piercing rounds with its PD rounds (and would similarly have had to intersperse its new PX round). FACC's system permitted FACC to use less expensive PD rounds for short-range and ground targets and save the more expensive PX rounds for long-range targets and hence reduce ammunition acquisition costs.[3] With FACC's system, DIVAD could be reloaded by hand in 13 minutes and automatic loading equipment was not necessary, thus giving FACC a potential support cost advantage. Some modifications to the Bofors gun

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[1]Based on Paul Carrick, op. cit., page 209-210.

[2]See J. Philip Geddes, op. cit., page 885-886 for a description of the FACC feed system.

[3]Discussions at FACC suggest that the feed system was not designed primarily to save PX rounds. Indeed, FACC even considered using only PX rounds in order to reduce logistics costs but determined that a PD round would still be important for ground targets.

were required in order to accommodate the FACC feed system and the fully automatic firing mode.[1]

In summary, the PX round is a highly cost effective feature of the Sgt. York System and its use is a benefit of the competition. The Bofors 40mm PX round, together with FACC's "fast bullet" modifications to reduce time of flight, enabled FACC to exceed the Army's gun performance expectations even without the more expensive closed-loop fire control method. The greater effectiveness of the PX round, aided by the round selectability of FACC's linear linkless feed system, permitted a large savings in ammunition acquisition costs despite the greater unit cost of the PX round.[2] By enhancing the viability of the 40mm gun as a candidate for DIVAD armament, the PX round also helped the Sgt. York take advantage of the support cost advantages of the gun's greater reliability and durability and its lack of need for a separate armor-piercing round. It is not known whether a 35mm system utilizing a PX round would have been as cost effective as the 40mm system, but GDP attested to the potential benefits of the PX when it decided to include such a round in its Phase 2 proposal. As discussed above, at the beginning of Phase 1 the Army was unconvinced of the merits of the PX round and leaned toward specifying the 35mm gun for which no PX had yet been developed. Competition forced the Army to keep the gun decision open, and it was FACC's drive for competitive

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[1]The Bofors gun had been fed manually before.

[2]The PMO has estimated that for the Sgt. York to achieve the same effectiveness using only PD rounds would increase ammunition cost by a minimum of $140 million (in escalated dollars).

advantage that caused the PX round to be improved, tested, and accepted for use on the DIVAD.[1]

5. Production Facilities

Both FACC and GDP made substantial investments in production facilities for the DIVAD. As noted above, the Phase 2 proposals were required to include firm ceilings for Government-funded special tools and special test equipment (ST/STE) unique to the DIVAD production program. The contractors were required in their production plans to detail the equipment and facilities they would use and in their management plans to indicate their intended capitalization. The ceiling prices in their production options included charges for their own capital costs.

Production facilitization became a competitive issue because the competitors had to convince the Army that they would be able to meet the demanding DIVAD production schedule.[2] GDP invested $40-50 million and had a brand new building in place prior to the source selection. GDP's investment and detailed production plan validated its ability to protect the DIVAD schedule.[3] FACC felt that it had to null out this potential GDP competitive advantage and fight the

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[1] In a paper competition, without prototype testing, FACC would have had great difficulty selling the merits of the PX rounds.

[2] The first production system was scheduled to roll out in the second half of 1983, two and one-half years after the Phase 2 source selection.

[3] Discussions at the PMO indicate that GDP's terms of acquiring the facility protected its interests in the event it lost the Phase 2 contract selection but that GDP is now making other uses of the facility.

image of being a bidder without facilities.[1] While FACC was conservative and did not invest in facilities until after the source selection, it proposed to spend $50.3 million of its own funds for DIVAD facilitization in Phase 2.[2] The commitment of company funds was also important to protecting the production schedule due to constraints on Government funding for DIVAD.[3]

While the competitive source selection process may have encouraged the competitors to risk their own funds on facilitization, the limited time horizon of Phase 2 and the Government's annual funding commitments may have limited facilitization investment below what was best. For example, it would evidently have been less costly if the guns for all 618 Sgt. York systems had been produced in the US rather than purchased overseas, owing to the greater mechanization of US production methods.[4] Due to start-up costs, however, US production would be more expensive for the quantities required during Phase 2 only.[5] The competitors did not propose to invest the additional $31 million required for US gun

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[1]Based on discussions at FACC.

[2]FACC's investment was not protected by a Government guarantee and its full recovery would depend on Phase 3 production contracts and foreign military sales.

[3]As noted above, budgetary problems had already caused a delay in the source selection itself.

[4]Discussions at FACC suggest $8-20 million could have been saved over the entire Sgt. York buy. Also, see Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Fiscal Year 1982, Part 2, March 16, 1981, page 165.

[5]FACC estimated that savings from US production would not be apparent unless 675 guns were produced, while the Phase 2 production options would require only 552 guns.

production at the beginning of Phase 2 and FACC has no competitive incentive to do so now.[1] If the Government had proposed to award a multiyear contract for the entire buy of 618 Sgt. York systems, there would have been additional opportunities for cost savings through contractor facilities investments.[2]

Phase 2 included a producibility engineering and planning (PEP) effort to improve production methods and prepare FACC's design for production. FACC's production facilities (including 523 thousand square feet) for the Sgt. York made extensive use of advanced equipment and methods in order to control production costs. Examples include:

- Yield is increased by prescreening every active electronic component (rather than only sampling each lot);
- The electronic assembly line is highly automated to improve yield and reduce labor costs;
- FACC allows the same employee team to stay with a gun system throughout its assembly, enhancing quality control awareness and reducing FACC's ratio of inspection to touch labor;
- Teams have been established for each LRU (i.e., line replacement unit) for a continuing effort to find ways to reduce production costs;
- Parts storage and retrieval are highly automated to provide labor and floor space savings as well as accessibility;

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[1]The technical data package required in Phase 2 must provide for the production (using US methods) of gun spares and the cannon as well as assembly of the complete gun. Also, preparation is underway to phase in U.S. production of the ammunition including both assembly and manufacture of the constituent parts and propellants.

[2]Discussions at FACC suggest FACC might have invested an additional $40 million in such a case. For example, investment to permit casting the turret would have reduced unit costs by $20-40 thousand.

- Extensive use was made of computer-assisted design (CAD) for tooling.

6. Subcontractors

FACC subcontracted approximately 60 percent of its FY 82 production contract. Most of the subcontractors were signed to fixed-price (FP) contracts although five of the larger subcontractors were awarded fixed-price-incentive (FPI) contracts, including largely the same terms and conditions as the Government's contract with FACC. Negotiations with the subcontractors had begun when they were selected for FACC's Phase 1 team. FACC assigned DTC bogies (i.e., goals) and pressured its subcontractors to achieve them, but FACC did not provide explicit financial incentives. FACC relied heavily on competition in selecting its subcontractors and, thanks in part to the use of mature components, had alternative vendors to choose from in most cases. Prior to the source selection, FACC obtained "handshake" agreements with its subcontractors on price and contractual terms and conditions.[1] The possibility of dual-sourcing the production of DIVAD components remains open for the future since the Government owns design modifications it paid for and has obtained licensing agreements to permit the production of contractor-owned designs.

Westinghouse is the largest subcontractor, accounting for 26 percent of the FY82 production award. Westinghouse had

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[1]For the most part these agreements worked out but in at least one case FACC was forced to change suppliers following the source selection. The vendor had sought a higher price and looser contractual requirements than had been agreed on, but FACC was able to switch to a vendor previously under contract to GDP. In another case, FACC switched vendors even prior to submitting its proposal.

developed the basic radar at its own expense and owned the rights to its designs. This gave Westinghouse a particular incentive to help FACC win the competition, and hence to control unit production costs as it modified the radar design for the DIVAD application. FACC assigned Westinghouse a difficult recurring unit cost bogie based on a comparison of the costs of other radar systems (including GDP's Phalanx radar). Westinghouse has had some difficulty controlling costs during initial production and is acquiring additional automatic test equipment in an effort to achieve target costs in succeeding contracts.

Bofors owns the rights to its basic gun design and would receive a four percent royalty on guns produced in the US for US use.[1] The Government owns the rights to gun modifications performed by Bofors to FACC's functional specifications. AAI Corporation won a five-firm paper competition for the right to design the turret for FACC during Phase 1 and then won a second competition for the right to produce the turret. The turret is a relatively simple structure to produce and a number of firms would readily bid to produce it even now.[2] Garrett Corporation provided auxiliary power units (APUs) for both GDP and FACC. Garrett established separate competing internal groups to make the required modifications for the respective DIVAD designs in order to control sensitive

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[1]FACC also negotiated a ceiling with Bofors limiting total royalties. See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Fiscal Year 1982, Part 2, March 16, 1981, page 162.

[2]Based on discussions at PMO. FACC's turret is fabricated from homogenized steel while GDP's, built by FMC, used more expensive honeycombed aluminum in order to reduce weight. Discussions at FACC suggest that FACC itself could have produced the turret but subcontracted it, in part, in order to avoid the additional capital risk involved.

information and hence be in a position to sell to whichever prime contractor won. The electronic fuse for the proximity round was supplied by Magnavox.

7. Competitive Cost Results

The DIVAD competition resulted in a substantial savings in unit procurement cost (UPC) compared to what would have occurred in a sole-source development program. This section examines alternative estimates of those savings.

Estimated UPC for Sgt. York decreased (in constant 1978 dollars) from $3.306 million to $3.263 million from the beginning of the competition until December 1982. If the UPC estimate had instead increased at the same rate (i.e., 5.8 percent per year) as UPC did for the median noncompetitive program discussed in Chapter III of the main report, it would now be 30.7 percent higher. Thus, the Sgt. York Program has demonstrated outstanding UPC control. This avoidance of cost growth resulted in an estimated procurement cost savings of $0.619 billion in constant 1978 dollars or $1.168 billion in escalated dollars. In addition to prototype competition, the savings can be attributed to the extensive use of mature components. But, as discussed below, competition had a major impact on motivating the contractors to implement the mature-components strategy. Including the 60-day extension of the DT/OT and interim contracts, the Phase 1 contracts directly cost the Government $43.4 million for FACC and $42.8 million for GDP.[1] A reasonable estimate of the incremental cost of

[1] It is not known to what extent other contractor DIVAD expenses were paid by the Government as part of overhead on contracts for other programs. The additional cost of the source selection process itself was offset by PMO personnel savings stemming from the "hands off" development approach.

competing the DIVAD ED is thus the average of the two Phase 1 contracts or $43.1 million. The estimated UPC savings amount to 27.1 times the incremental costs of competition in escalated dollars. In constant 1978 dollars, the comparable ratio is 16.0. If the constant-dollar estimates are discounted[1] to take into account the fact that competition requires up-front funding but the savings will occur only in the future, the ratio is still 9.9.[2]

During Phase 2, the Army observed:

> In addition, the benefits of total competition between Ford Aerospace and General Dynamics reduced the procurement costs of the program by an estimated 25 percent.[3]

In the December 1981 Selected Acquisition Report, the PMO indicated that it was reducing its procurement cost estimate by $196.8 million (in constant 1978 dollars) or $318.4 thousand per unit as a result of the selection of the FACC system. Previous estimates had been based on a generic system that reflected the likely characteristics of both contractors' designs. This 9.2 percent reduction in the then-current estimate understates the full impact of competition since the generic estimate itself would typically have grown during the development phase.

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[1] As discussed in Chapter V of the main report, a ten percent rate is used to discount the constant dollar savings and incremental costs back to the base year.

[2] This exemplifies the tremendous leverage possible when R&D costs are low relative to procurement costs. Also note that these calculations conservatively assume that in future years, DIVAD's UPC estimates will increase at the same rate as those of an average noncompetitive program.

[3] See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Fiscal Year 1983, Part 3, March 18, 1982, page 790.

The Army currently estimates unit "flyaway" costs at $1.82 million (in constant 1978 dollars) as compared to the DTC goal of $1.90 million. This represents a noteworthy achievement. Table C-4 compares unit hardware cost (a major determinant of flyaway costs) growth for the major DIVAD subsystems and reflects the DTC effort discussed in previous sections. The armament data indicate that the original estimate was achieved despite improvements such as FACC's dual feed system (and do not include savings in ammunition costs). Estimated ammunition costs (including initial production facilitization) have declined from $394.2 million (in constant 1978 dollars) to $323.5 million from the beginning of Phase 1 to December 1982, a savings of $114.4 thousand per fire unit.[1] As noted above, the ammunition savings are largely due to reduced quantities required thanks to the effectiveness of the 40mm PX round.[2] Further, as discussed above, substantial costs have been avoided as a result of the flexibility accorded the contractors to make cost/performance trade-offs during the competition. As the project manager observed:

> If in the requirement document we saw something that we felt was not really needed and we could save a lot of money, we were able to make those cost performance trade-offs... We saved approximately

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[1]Based on Selected Acquisition Report (U), December 1982. SECRET. (Information derived for the report is Unclassified).

[2]The PMO has estimated that to achieve the same effectiveness for the 40-mm gun with only point-detonating (PD) rounds would cost at least $140 million more.

Table C-4. UNIT HARDWARE COST GROWTH (MILLIONS OF CONSTANT 1978 DOLLARS)

SUBSYSTEM	DEVELOPMENT ESTIMATE (NOVEMBER 1977)	CURRENT ESTIMATE (DECEMBER 1982)
Fire Control	.79	.65
Turret/Drive	.29	.19
Armament	.26	.26
Vehicle Modifications	.08	.12
Integration and Assembly	.05	.01
Government-Furnished Chassis	.24	.18
Total Unit Hardware Cost	1.71	1.41

Source: Based on information provided by Sgt. York Project Management Office (PMO).

> $400,000 per fire unit by making those trade-offs which have proved to be acceptable to the user.[1]

Thus, the competitively motivated DTC effort has avoided the cost growth typical of a system that has not undergone prototype competition and has even achieved cost reductions (from the PMO's original estimates) for areas such as fire control and ammunition.

What is more, the current UPC estimates for the Sgt. York are, to a substantial degree, contractually guaranteed. As discussed above, the Phase 2 contract included competitively negotiated, firm ceiling prices covering production options for 45 percent of the total procurement quantity as well as ammunition and spares and repair parts to support the options and the Government's portion of production facilities costs. The ceiling prices not only protected the Government's interests but also provided FACC with a continuing motivation to control unit costs and make its optimistic estimates come true during the critical Phase 2 period of design maturation, producibility engineering and planning (PEP), and production initiation. It can be presumed that the ceiling prices were based on optimistic cost estimates since at least the first option is expected to reach this ceiling. Further, as the Army observed:

> We believe that the competition aspect of the program has caused the contractors to shave their bids very carefully... This has driven, we believe,

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Fiscal Year 1983, Part 3, March 18, 1982, page 816. In constant 1978 dollars, this savings would be roughly equivalent to $220,000.

through the competition factor, the prices to a reasonable point.[1]

There do not appear to be any major Government changes in requirements or schedule on the horizon that could invalidate the options. The UPC estimates, however, are still subject to revision based on the uncertain outcome of negotiations for Phase 3 production contracts. Phase 3 prices should be tempered by the fact that the Government will have a good deal of information on the learning curve FACC is achieving in Phase 2 and by the existence of a technical data package (TDP) that gives the Government the option of competing the Phase 3 award.[2]

The broad scope of the ceiling prices was particularly advantageous. The ceiling prices included the costs of expensive classroom trainers and peculiar support equipment even though the Government did not pay the contractors to develop such items during Phase 1. The contractors, nevertheless, both used their own funds to develop these items to the point that they could prudently bid on them.[3] The inclusion of spares and repair parts similarly extended the

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 2970, Part 2, March 16, 1981, page 163.

[2]Further, discussions at the PMO suggest that it was conservative in revising its UPC estimates to reflect the savings estimated by FACC.

[3]Discussions at FACC indicate that, while FACC had allocated $9 million to the classroom trainer, initial subcontractor bids put the cost at $21 million and forced FACC into a cost-scrubbing exercise even though the competition had ended. Use of production hardware for the trainer did help FACC to predict and control its costs.

impact of the competitive bidding.[1] The provision for total system responsibility including the correction of design deficiencies at contractor expense closed yet another avenue through which procurement costs might have escalated.

Other cost benefits of the competition included FACC's agreement to fund some $21 million in anticipatory costs in order to protect the production schedule. That is, FACC obtained approval to incur expenses for which the Army had not yet provided funds but which would later be reimburseable. This amounted to a loan to the Government but exposed FACC to a substantial risk in the event that the program were cancelled.[2] Further, the contractors were forced to absorb substantial costs related to the preparation of their proposals for Phase 2, since this was not included as a line item in the Phase 1 contracts.

Clearly, the Phase 1 competition had a substantial impact on controlling unit procurement cost. Design innovations and cost/performance trade-offs resulted in a system design with the potential to meet the Army's original estimate of unit procurement cost (UPC), and the firm Phase 2 price ceilings provided FACC with a continuing motivation to realize that potential as the system transitioned into production. While the use of mature components made a major contribution to the control of UPC cost growth, competition in turn forced the contractors to rely heavily on mature components. They had to control cost and schedule risks in order to win as well as

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[1]A separate contract was later negotiated when the Army determined that it needed more spares than FACC had proposed, but the ceiling price for the initial quantities was preserved.

[2]Anticipatory expenditures were in addition to the usual Government-funded acquisition of long-leadtime items (LLTI).

profitably implement the Phase 2 production options. It cannot be known what UPC cost growth would have been in a sole-source DIVAD development. To what degree would the development contractor have responded to Army demands for maximum possible reliance on mature components rather than enhance its own capabilities by developing new advanced components? And to what degree would the contractor have controlled UPC in order to save DIVAD from cancellation rather than permit its fee (ultimately based on system costs) to grow? What is known is that such considerations have not kept the average noncompetitive program's UPC from growing at 5.8 percent per year (before inflation).

8. Other Results

Did the Sgt. York Program achieve its objectives for schedule and technical performance? Initial operational capablity (IOC) is now scheduled for March 1985, 7.3 years following DSARC 2 and the approval of engineering development (ED). This is slightly above average in duration[1] and includes a 17-month delay from the original schedule.[2] A two-month delay resulted when prototype immaturity extended the DT/OT at the end of Phase 1. The Army extended its source selection decision by another five months due, in part, to budgetary uncertainty. Budgetary problems also delayed initial production from FY81 to FY82, causing the remaining

[1] Those systems currently reporting in the Selected Acquisition Reports that have reached IOC averaged 6.8 years.

[2] See Comptroller General of the United States, "Tests and Evaluations Still in Progress Should Indicate Division Air Defense Gun's Potential Effectiveness" (U), page 17. SECRET. (Information derived for this report is Unclassified).

10-month IOC delay.[1] The noteworthy feature of the DIVAD schedule is that it is being achieved without a preceeding advanced development (AD) phase, thanks to the use of mature components.

While the Sgt. York Program has experienced some of the usual technical problems during Phase 2, the system is expected to work as advertised. The current Selected Acquisition Report (SAR) asserts that the Sgt. York "will highly satisfy current mission requirements."[2] The SAR further indicates that reliability and maintainability requirements will be met or surpassed. Phase 2 was planned to include a six-month maturation effort to correct problems identified at the Phase 1 DT/OT.[3] Most notably, these included redesigning the turret to reduce weight and the PX round to reduce time of flight as well as correcting software problems related to reaction time and other difficulties. A three-month check test ending in January 1982 verified that 11

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[1]Worries over excessive concurrence of production and development may also have contributed to the delay in initiating production. See, for example, Comptroller General of the United States, op. cit., SECRET. Concurrency risks might have been reduced by increasing testing and addressing more logistics issues during Phase 1. But that would have meant an additional $20-40 million to each Phase 1 contractor (based on discussions at PMO). (Information derived for this report is Unclassified).

[2]See Selected Acquisition Report (U), December 1982. SECRET. (Information derived for this report is Unclassified).

[3]Phase 2 R&D efforts also included integrated logistics support (ILS) development, enhancement of reliabilty and maintainability, and preparation of the technical data package (TDP).

out of 12 performance checks were satisfactory.[1] The principal remaining problems involved the interface of the identification-friend-or-foe (IFF) system with the radar and reliability problems with the ammunition feed system. Corrections to both of these problems have been demonstrated. A noteworthy aspect to this and other design problems is that the costs of correcting them are included in the fixed-price ceilings of the Phase 2 R&D and production contracts.[2]

E. CONCLUSION

The DIVAD development program was eminently successful at controlling unit procurement cost (UPC). Estimated procurement costs were reduced by 30.7 percent because the UPC estimate actually declined since the beginning of development rather than increase at the rate typical of programs without prototype competition. The estimated savings were 27.1 times greater than the additional costs attributable to competition. If the cost and savings estimates are adjusted for inflation and discounted to reflect the fact that the costs are incurred up front while the savings are realized only in the future, the savings still outweigh the costs 9.9 times.

Much of the savings can be attributed to the Army's decision to utilize mature components as much as possible. This decision accounts for the low level of R&D costs relative to procurement costs and for the tremendous leverage that

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[1]See Committee on Armed Services, House of Representatives, Hearings on Military Posture and H.R. 5968, Fiscal Year 1983, Part 3, March 18, 1982, page 814-815.

[2]Under total system responsibilty, FACC has guaranteed that the performance and reliabilty and maintainability requirements will be met.

resulted for R&D efforts to control UPC. Reliance on mature components also had a direct impact on reducing UPC growth. But competition played an important role in motivating the development contractors to adhere to the mature-components strategy. Further, competition motivated a strong design-to-cost (DTC) effort that led to specific design innovations and cost/performance trade-offs in order to achieve unit cost objectives. And the requirement that the competitors propose firm ceiling prices covering almost all procurement costs for 45 percent of the total planned DIVAD quantities motivated the contractors to be realistic in their DTC estimates and pressured the winner to make its estimates come true as the design was transitioned into production. Thus, while not all of the 30.7 percent UPC savings can be attributed to competition, it is clear that the prototype competitive saved much more than it cost.

Appendix D

AGM-86B AIR-LAUNCHED CRUISE MISSILE

APPENDIX D

AGM-86B AIR-LAUNCHED CRUISE MISSILE

A. INTRODUCTION

The Air-Launched Cruise Missile (ALCM) Program utilized competition extensively in both its development and its procurement phases. The ALCM engine and the guidance hardware both underwent competitive advanced development programs including prototype fabrication and testing; both subsystems are being procured from dual, competitive sources. This study, however, concentrates on the development of the ALCM airframe. The airframe experienced advanced development in a basically sole-source environment but then was the subject of an intense and especially well-structured full-scale development competition, including competitive pilot production. Thus, the airframe development provides a unique opportunity to view a development program both before and after the application of competitive incentives.

The ALCM discussion is organized as follows:

- Section B provides background information on the weapon system, its program history and its acquisition strategy;
- Section C discusses incentives to control procurement costs provided by the structure of the competition;
- Section D discusses the impact of the competition on system design and eventual procurement costs; and
- Section E present concluding remarks.

B. BACKGROUND

1. Mission and System Description

The ALCM is an air-to-ground missile designed for launch (both internally from the bomb bay and externally from wing pylons) from B-52 and B-1 bombers. The ALCM's mission is strategic; it can carry its nuclear warhead over 1500 miles with remarkable accuracy. Its range permits it to be launched from stand-off (i.e., outside Soviet air space) as well as penetrating aircraft. The ALCM is powered by a miniature turbofan engine and is guided by a radar-dependent, terrain-following TERCOM guidance system. The Boeing Aerospace Company produces the ALCM, fabricating the airframe and certain subsystems and integrating the Government-furnished engine and guidance hardware. The Boeing ALCM is designated AGM-86B.

During full-scale development, the AGM-86B competed with the AGM-109 Tomahawk Cruise Missile developed by the General Dynamics Convair Division. The Tomahawk, which utilizes the same engine and guidance hardware as the ALCM, was developed for the Navy's Sea-Launched Cruise Missile (SLCM) Program for launch from submarine torpedo tubes and from surface ships. In addition, the Tomahawk is being utilized by the Air Force for its Ground-Launched Cruise Missile (GLCM) Program.

2. Early Program History

Although the formal competition between the Boeing ALCM and the General Dynamics Tomahawk was not directed until September 1977, their prior development programs had closely paralleled one another. As indicated on Table D-1, predecessor programs for both the ALCM and the SLCM were initiated in 1972. The Air Force's Subsonic Cruise Armed

Table D-1. EARLY CHRONOLOGY FOR ALCM AND SLCM

DATE	ALCM EVENT	SLCM EVENT
Early 1972	SCAD Program Initiated	
June 1972		SCM Program Initiated
November 1972	SCAD Program Cancelled	
February 1974	DSARC I Approves ALCM Advanced Development	DSARC I Approves SLCM Advanced Development
December 1974	DSARC Cancels ALCM Program	
March 1975	DSARC Reinstates ALCM Program	
February 1976	First ALCM Flight	
March 1976		First SLCM Flight
January 1977	DSARC II Approves ALCM Full-Scale Development	DSARC II Approves SLCM Full-Scale Development

Decoy (SCAD) Program included a (largely paper) airframe competition won by Boeing (over Lockheed) and an engine competition won by Williams (over Teledyne). After the July 1973 cancellation of the SCAD Program, its airframe became the basis for the ALCM airframe, and its engine was developed for use by both the ALCM and the SLCM. The Navy's Strategic Cruise Missile (SCM) Program envisioned missiles launched vertically from Polaris submarines among other options, but was soon replaced by the SLCM Program for land attack and antiship missiles launched from torpedo tubes and other platforms. Both the ALCM and the SLCM Programs received DSARC approval for advanced development in February 1974 and for full-scale development in January 1977.

Boeing began its advanced development (AD) effort in July 1974, following studies to validate the ALCM concept. The CPIF contract required the design and fabrication of seven prototype missiles. Seven test flights were launched from a modified launcher in the bomb bay of a B-52, beginning in March 1976. The AD was conducted in order to demonstrate airframe aerodynamics and the operation of the engine and the guidance system as well as to develop specifications for the FSED phase. The AD prototypes were not designed to military specifications and no design-to-cost (DTC) goal was pursued.

The parallel ALCM and SLCM development programs gave rise to both cooperative and competitive features. A high degree of commonality developed among ALCM and SLCM subsystems due, in part, to continuing pressure from OSD. Joint Air Force/Navy programs had begun as early as 1972 for the engine and guidance system. By January 1974 the Air Force was the lead Service to develop the engine for both ALCM and SLCM, while the Navy was lead Service for the guidance system. Similarly, a common nuclear warhead was developed. These components are now basically common for ALCM and SLCM, although there are differences in their configurations due to differences in the ALCM and SLCM airframes and missions. As a result, substantial cost savings have been achieved in both development and procurement. In early 1977, a Joint Cruise Missiles Project Office (JCMPO) was established to manage both ALCM and SLCM (and other cruise missile programs) in order to preserve and promote commonality.

The existence of separate ALCM and SLCM Programs was originally based on the different airframe constraints imposed by the respective missions and launching modes of the two systems. The ALCM was intended for use on penetrating bombers (i.e., B-52, B-1) and was required to be compatible with launch from the internally carried rotary launcher used for the AGM-69A Short Range Attack Missile (SRAM). Thus, the ALCM AGM-86A was constrained to a maximum length of approximately 14 feet. The SLCM was planned for launch from submarine torpedo tubes, and hence was constrained to a diameter of 21 inches and a length of approximately 21 feet. Further, the SLCM mission of providing a stand-off land attack capability dictated that the missile take advantage of the additional fuel capacity and range permitted by greater missile length. The different launch modes and environments dictated other design differences between the ALCM and SLCM. For example, the ALCM must accommodate a severe environment (e.g., radiation, extreme temperature changes) and must be compatible with SRAM on-board and ground support equipment. The SLCM requires a rocket booster (to reach a sufficient air speed for the turbofan engine to operate) and individual launch canisters, and must withstand shock from depth changes.

This rationale for maintaining separate development programs (i.e., that different missions required different airframes), however, was never totally compelling. Indeed, the possibility of using a SLCM airframe for the ALCM role was debated from the beginning, and repeated attempts were made to do just that even prior to the formal FSED competition. Using a common (or nearly common) airframe offered the potential for cost savings through economies of scale in manufacturing as well as through spreading contractor overhead over more units. Eventually even the launch platform constraints changed.

After cancellation of the SCAD Program, Deputy Secretary of Defense William P. Clements, Jr. signed an August 14, 1973 decision paper directing the Navy to proceed into advanced development of a cruise missile system. The Navy was to defer launch platform decisions since it appeared "feasible to develop a missile for modifications for launch from sea, air and land platforms."[1] In February 1974, DSARC I approved advanced development for separate ALCM and SLCM programs. While the Navy would not build an air-launched version, it would initially test SLCM (for reasons of convenience) by air launch from an A-6. In December 1974 the DSARC cancelled the ALCM Program and instructed the Air Force to use a modified SLCM. While this decision was soon reversed, a March 18, 1975 DSARC affirmed the competitive nature of the advanced development programs. Dr. Malcolm R. Currie (Director of Defense Research and Engineering) described the decision to maintain a competitive environment between Navy and Air Force contractors (in addition to the air vehicle competition being conducted by the Navy for the SLCM) in order to validate and minimize production and other follow-on costs. He noted that:

[1]See Aviation Week and Space Technology, August 20, 1973, page 24.

> ... it is in the advanced development stage that expenditure levels are sufficiently low that we can afford to keep all viable options open--so that the truths of cost and performance can be brought out clearly in an environment which is as competitive as practicable....The two-program advanced development approach seems appropriate to be continued until we have demonstrated the cruise missile concept and illuminated reliable cost and performance data. At that time, sufficient information should be available to decide whether to continue with two programs, consolidate into a single integrated program, or pursue another alternative not presently perceived.[1]

In order to further the competitive atmosphere, the SLCM milestones were to be aligned with those of the ALCM Program and the SLCM was required to be compatible with launch from the B-52.

By this time, the potential competition between the SLCM and ALCM for the air role was evolving in two directions. On the one hand, a scaled-down (154-inch) version of the SLCM was fitted to the SRAM rotary launcher. This version would have approximately the same range as the proposed ALCM. On the other hand, Boeing proposed carrying a belly tank beneath the ALCM in order to double its range (from approximately 600 to 1200 nautical miles).[2] This would make the ALCM more competitive with the standard, 219-inch SLCM (with a range then estimated at approximately 1600 nautical miles) in the event that a stand-off ALCM (requiring greater range after

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[1]See Aviation Week and Space Technology, April 21, 1975, page 9.

[2]The Air Force originally restricted the ALCM range since the B-1 was being developed as a penetrating bomber and precluded the need for an ALCM with stand-off range. See Robert J. Art and Stephen E. Ockenden, "The Domestic Politics of Cruise Missile Development, 1970-1980," page 370.

launch from a nonpenetrating aircraft) should be required.[1] While these proposed modifications indicate that DoD and the contractors were aware that the SLCM might compete for the air-launched role, the ALCM flight test program concentrated on the standard version launched from a SRAM rotary launcher, and the SLCM Program flew its standard, full-size version (without mating it to a B-52).

By the end of 1976, as the DSARC-2 milestone approached for the ALCM and the SLCM, DoD was again reviewing the potential use of the SLCM for launch from a B-52. A 154-inch SLCM had undergone wind tunnel testing and had a potential range of 1000 nautical miles, but at most seven such missiles could be carried by the SRAM rotary launcher (as opposed to eight ALCMs). If the rotary launcher were removed, nine 219-inch SLCMs could be carried in the B-52 bomb bay in addition to 12 carried externally on wing pylons. At the same time, a stretched version of the Boeing ALCM was considered to increase its range. There was a strong possibility that the General Dynamics Tomahawk SLCM would be chosen by DSARC 2 for full-scale development for the air-launched role. The Tomahawk would have 84 to 92 percent commonality between its air and sea versions, and its selection could save the estimated $300 million full-scale development cost of the Boeing ALCM.[2] Nevertheless, the January 1977 DSARC 2 approved the full-scale development of the Boeing ALCM for the air-launched role and of the General Dynamics Tomahawk for the SLCM role. It was felt that requiring a common airframe might "impose (an) unwarranted and unnecessary performance

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[1] See Aviation Week and Space Technology, March 31, 1975, page 13.

[2] Ibid., November 22, 1976, page 16.

compromise."[1] Priority in the ALCM Program was to be given to developing the stretched, 1200-nautical-mile version.[2]

Thus, the advanced development phase of the ALCM Program was competitive in the sense that there was always a credible possibility that the Boeing ALCM would be replaced by a variant of the SLCM. Indeed, the December 1974 DSARC and (on October 2, 1975) the House of Representatives (temporarily) made precisely that decision.[3] A SLCM variant was a credible threat to the Boeing ALCM because of the high degree of commonality it would have with the SLCM airframe being developed anyway. This could provide substantial cost savings in both full-scale development and procurement. In addition, the greater demonstrated range of the SLCM made it a stronger candidate to perform the increasingly important ALCM stand-off role.

On the other hand, the ALCM advanced development program was in fact sole-source. Boeing tested seven missiles designed to be launched from the SRAM rotary launcher of a B-52. The proposed 154-inch SLCM was not flown and only seven of these missiles could have been fitted to the SRAM rotary launcher (as opposed to eight ALCMs). No SLCM (of any length) had actually demonstrated a launch capability from a B-52. Thus, competition of the SLCM for the ALCM role remained only potential throughout advanced development. No SLCM contractor was paid to go head-to-head with Boeing in developing a

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[1]See Aviation Week and Space Technology, January 24, 1977, page 17.

[2]DSARC 2 also approved full-scale development of a Tomahawk Ground-Launched Cruise Missile (GLCM) for the Air Force.

[3]See A.A. Tinajero, "Cruise Missiles (Subsonic): U.S. Programs," January 18, 1978, page 17.

missile for the ALCM role (as had occurred between LTV and General Dynamics in advanced development for the SLCM role).

It is not clear how much pressure the potential competition described above placed on Boeing to control eventual production costs. Certainly, this was an explicit DoD objective as evidenced by the Malcolm Currie statement quoted above. Still, Boeing did not submit a production proposal or commit itself to a fixed price at the end of advanced development and the AD prototypes were designed primarily to demonstrate performance. Thus, even if Boeing took the threat of competition seriously, it may not have viewed estimated unit procurement cost as a decisive factor in the selection of an ALCM candidate for full-scale development. Boeing's advantage was that it had tested a design tailored to the Air Force's specific requirements.

3. Introduction of Competitive Full-scale Engineering Development

Full-scale engineering development (FSED) of the ALCM began with the award of a sole-source CPFF contract to Boeing in March 1977. The FSED was to include design and fabrication of 22 missiles for 23 test flights (i.e., a parachute recovery system would permit the missiles to be reused). Fourteen extended-range versions and eight standard versions (similar to the AD missiles) would be developed, with the extended-range missiles to be developed first. The stretched version would be launched only from B-52 wing pylons since it would not fit the rotary launcher in the bomb bay, which would continue to be used to launch the standard ALCMs.

With the cancellation of production for the B-1 bomber (announced by President Carter on June 30, 1977), greater reliance was placed on cruise missiles for strategic deterrence and the dates required for initial operational capability were advanced by a year or more for both the ALCM and the SLCM. Without the B-1, the Air Force's planned penetrating bomber capability was greatly reduced. This increased the range required from the ALCM so that it could be launched from stand-off aircraft (i.e., outside Soviet air space) and still be able to reach the required targets.[1] The AGM-86A flown by Boeing during advanced development had a range of only 600 nautical miles. The extended-range design initiated by Boeing for FSED was expected to achieve a range of 1200 nautical miles by adding five feet to the missile length to increase fuel capacity. But engineering drawings for the extended-range version were not released until July 1977 and this model had never been fabricated. In comparison, the Tomahawk Cruise Missile in full-scale development at General Dynamics for the SLCM role had a range of up to 2000 nautical miles and had undergone an extensive flight test program. Since even the 1200-mile range of the extended-range ALCM might prove inadequate[2] and since it would not have the advantage of fitting the SRAM rotary launcher anyway, there was a strong case for terminating the Boeing program and using the Tomahawk for the ALCM role.

Nevertheless, there were certain drawbacks to selecting the Tomahawk. Although it had been tested extensively by air launch from an A-6 aircraft, it had not been launched from or designed for integration with the B-52. Other than its range advantage, the Tomahawk was not necessarily a better missile. Further, there was political pressure to save the

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[1]See Aviation Week and Space Technology, July 11, 1977, page 14-16.

[2]Ibid., page 16.

Boeing program. On June 21, 1977 the conference report for the FY78 DoD Authorization Bill required DoD to retain competitive cruise missile development programs until it could certify that a single airframe would meet all operational requirements and that terminating the competitive programs would reduce development and procurement costs.[1]

In July 1977 the President requested that Congress increase FY 78 funding by $449 million in order to accelerate cruise missile development and to initiate a competitive full-scale engineering development (FSED) program and flyoff for the ALCM.[2] The testimony of DoD officials in support of this request illuminates the rationale and the objectives of the competition. The director for the Joint Cruise Missiles Project Office, (then) Captain Walter M. Locke, referred to the impact of accelerating the ALCM development program:

> This program does have concurrency in it. But if we are to meet the threat of the 1980s, we need that sort of concurrency. It is technically a low-risk program. So I think the concurrency is reasonable. It does have a cost and schedule risk associated with it. That is one of the principal reasons for the competition.[3]

Lt. Gen. Alton D. Slay, then Deputy Chief of Staff (Research and Development), US Air Force, also emphasized the risk of cost growth:

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[1]See A.A. Tinajero "Cruise Missile (Subsonic): U.S. Programs," January 18, 1978, page 14.

[2]This request accompanied the request to delete some $1.4 billion for the B-1, suggesting that the B-1 cancellation may have made the ALCM competition affordable as well as necessary.

[3]See Committee on Armed Services, US House of Representatives, Hearings on H.R. 8390, September 9, 1977, page 284.

> It is felt that a competitive full-scale engineering development program provides the Government with the greatest insight into schedules, technical performance, and life cycle costs before committing to a single approach. The value of competition can therefore be viewed quantitatively as a trade-off between the cost of continuing the competition and the risk of cost growth remaining in the program.[1]

Finally, William J. Perry, then Director of Defense Research and Engineering, defended the competition:

> First of all, because of the importance of this program, we feel that it is desirable to do the development of two of them in parallel as a hedge against failures in one of them. That is a small risk but nonetheless it exists. Second, and more importantly, is the point that Captain Locke made. We believe that a $300 million investment in the second missile and conducting it through its flight tests will save money in the program in the long term, that the advantage of the competition will not only get us a better performing missile, but it will get us a lower cost production unit...[2]

In summary, the ALCM flyoff was directed in order to manage the cost and schedule risks inherent in a program of the highest national importance. Those risks had been aggravated by program acceleration as well as by changes in the missile requirements from those that the respective ALCM

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[1]See Committee on Appropriations, US House of Representatives, Hearings on Fiscal Year 1978 Appropriations, Part 7, September 20, 1977, page 170.

[2]Ibid., page 329.

and SLCM Programs had addressed during advanced development.[1] DoD anticipated that the competition would result in a better missile and would lower unit procurement costs (compared to what they would have been in a sole-source environment).

4. Acquisition Strategy

The competitive, CPFF FSED contracts were not awarded to Boeing and General Dynamics until February 1978, due to a delay in obtaining Congressional approval of the requisite funding. The contracts called for the design and fabrication of prototype missiles to support a competitive development/operational test (DT/OT) program between July 1979 and February 1980 (see Table D-2 for a chronology of FSED events). Ten test flights were required and Boeing fabricated 12 prototypes, reserving two for ground tests. General Dynamics fabricated only seven flight prototypes (both contractors developed parachute recovery systems so that test missiles could be reused). The FSED phase also included the design and testing of required operational support equipment needed prior to ALCM launching. It was intended that the FSED missiles be preproduction prototypes so that full-scale production could be initiated immediately following the FSED phase.

In addition to the preproduction prototypes used for the test flights, each contractor was awarded pilot production contracts for 12 missiles for each of FY78 and FY79. According to the Request for Proposals (RFP) for the FY80 and FY81 buys:

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[1] For example, only a long-range ALCM version would now be developed and it would not be required to fit the SRAM rotary launcher.

Table D-2. CHRONOLOGY FOR ALCM FLYOFF

DATE	EVENT
January 1977	DSARC II approves full-scale development of ALCM by Boeing and of SLCM by General Dynamics.
February 1977	Full-scale development contract awarded to General Dynamics for SLCM.
March 1977	Full-scale development contract awarded to Boeing for ALCM.
June 1977	B-1 production cancelled.
July 1977	President requests $449 million from Congress to accelerate cruise missile development and initiate competitive full-scale development program for the ALCM.
September 1977	Under Secretary of Defense directs that ALCM flyoff be conducted.
February 1978	Contracts awarded to Boeing and General Dynamics to initiate competitive full-scale development of ALCM.
September 1978	Boeing and General Dynamics initiate FY78 pilot production of 12 missiles each.
February 1979	Boeing and General Dynamics initiate FY79 pilot production of 12 missiles each.
July 1979	First test flight (of full-scale development prototype missile) for ALCM competitive flyoff.
October 1979	Best and final offer proposals submitted by Boeing and General Dynamics for FY80, FY81 production contracts.
February 1980	Final test flight for ALCM competitive flyoff.
March 1980	Boeing selected as winner of ALCM competitive flyoff.

The FY78 and FY79 pilot line production program has the primary objective of demonstrating the capability of both competitors to produce the ALCM under an actual production environment. This information will be utilized as part of the source selection.[1]

The pilot line production was also intended to provide a warm base from which to expand ALCM production and to permit attainment of a First Alert Capability (i.e., one B-52 equipped with 12 ALCMs) by September 1981.[2]

The principal subjects of the competition were the airframe and its integrated launch from the bomb bay and wing pylons of the B-52. Both Boeing and General Dynamics used the Williams F-107 turbofan engine. McDonnell Douglas provided and integrated the hardware (built in turn by Litton and Honeywell among others) and software for the Tomahawk guidance system, but provided only the guidance hardware for Boeing's entry. Boeing insisted on providing its own software and integration, and was thus in competition with McDonnell Douglas as well. Both Boeing and General Dynamics were required to design and fabricate internal launchers (the SRAM rotary launcher being too short) for use on B-52s during the flyoff, although internal launchers were not included in the follow-on production proposals. General Dynamics subcontracted with Rockwell to provide its internal launcher while Boeing provided its own. The development contract for

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[1]See Request for Proposal for FY 80/81 Production, N00019-79-R-1000, December 22, 1978, page 2-13.

[2]The FY78 and FY79 pilot production contracts were awarded in August 1978 and February 1979. The first FY78 missile was not delivered until August 1980, after the source selection. Boeing's pilot production missiles were used to equip a B-52 at Griffis Air Force Base by September 1981 and are still in use as test vehicles.

the jettisonable wing pylons was awarded on a sole-source basis to Boeing's Wichita Division. Since these were required for external B-52 launch during the flyoff, Boeing-Wichita provided hardware modifications and software to accommodate both the Tomahawk and the Boeing ALCM.

As noted above, the ALCM Program involved some concurrency and hence cost and schedule risk, while technical risk was considered to be low. The contractors were allowed to make trade-offs in bands between operational requirements and goals in order to control unit costs. A design-to-cost (DTC) ceiling of $670 thousand (in constant 1977 dollars) was established for unit flyaway cost, although no DTC incentive fee was provided.

5. Conduct of Competition

The overall competitive program was managed by the Joint Cruise Missiles Project Office (JCMPO) in much the same manner as a normal FSED program. In reviewing contractor efforts, the JCMPO advised them when their designs appeared to fall short of requirements, but did not discuss how to correct those designs. Further, the JCMPO did not serve as a conduit for information between the competitors.

The missile evaluation program included ground tests, captive flights on B-52s, and ten free flights (per contractor) including both internal and external B-52 launches. Boeing and General Dynamics formulated their own test programs so as to demonstrate the performance characteristics established by the JCMPO, such as a range of 2500 km (1553 miles) at speeds up to 550 mph.[1] The JCMPO did

[1]See Aviation Week and Space Technology, January 29, 1979, page 147.

not define specific performance points to be demonstrated on particular flights. The flight tests combined both developmental and operational tasks and included participation by Strategic Air Command (SAC) crews and mission planners. The contractors themselves stationed 80-100 employees at Edwards Air Force Base where the test flights, involving three B-52s, were staged.[1] In order to reduce misunderstandings, the JCMPO negotiated memoranda of agreement with the contractors to establish ground rules for conducting the flyoff including contingency planning, information transfers, and system corrections.

The cost of conducting the competitive FSED program for the ALCM was substantial. When the competition was initiated, it was estimated that before selection of a winner incremental R&D costs would be $313.5 million for the Boeing ALCM, and $201.2 million for the General Dynamics Tomahawk. Incremental costs would be less for the Tomahawk since it would benefit from the ongoing SLCM R&D program. In addition, $95.8 million would be awarded to each contractor for pilot production. Thus, if the competitive program had not taken place the savings would have been $297 million for eliminating the Tomahawk or $409.3 million for eliminating the Boeing entry.[2]

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[1] Ibid., July 30, 1979, page 14-15.

[2] See Committee on Appropriations, US House of Representatives, Hearings on Fiscal Year 1978 Appropriation, Part 7, September 20, 1977, page 170.

C. COMPETITIVE INCENTIVES TO CONTROL COST

1. Value of Winning

Did the contractors want to win badly enough that the incentives of the competition mattered? Certainly the program size was substantial--at the beginning of the competition in 1978, Air Force plans called for total procurement of 3,418 ALCMs at a cost of almost $3.3 billion.[1] In Congressional testimony, General Slay described the contractor attitudes as follows:

> I set great store by the amount of worry that we engender in the contractors. And they are both worried and they are both pounding the halls trying to convince everybody that they are doing all that they can to shave their program costs and to give us the best. I really believe that we have the best situation now for a major competition that I have seen in a long time. I know that Boeing, on the one hand, is working and burning the midnight oil to upgrade their missile to give us a better missile at a more competitive cost, simply because they know that General Dynamics, having the background of 1200 missiles they are going to build for the Navy, has a leg up on them as far as ... overhead is concerned. So I think we will have a very, very good competition.[2]

In addition, the Boeing Aerospace Company was hungry since it had gone through "a long dry spell during which it failed to obtain any substantial new military programs, and its share of total Boeing business [had] steadily declined to ten

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[1] See the Selected Acquisition Report (U), December 1982. SECRET. Information derived for this report is Unclassified.

[2] See Committee on Appropriations, US House of Representatives, Hearings on Fiscal Year 1978 Appropriations, Part 7, September 20, 1977. page 331.

percent."[1] General Dynamics was in a more comfortable position since its role as SLCM developer was not being challenged.

2. Credibility of Competitors

The competitors were well-matched. Boeing had successfully completed its advanced development (AD) test flight program and had gained considerable experience at integrated B-52 launches. The company also may have had an advantage in promoting commonality between SRAM and ALCM support equipment. For its part, General Dynamics had already won the SLCM AD competition and had some experience air-launching its missile from A-6s. General Dynamics' sole-source position as SLCM developer (with a potential for 1200 production missiles) might have given it a production cost advantage through the sharing of fixed costs between the two programs. Further, because both contractors would use the same engine and guidance hardware, the scope for technical differentiation of the two missiles was importantly constrained. Thus, it could be expected that the Boeing and General Dynamics ALCMs would satisfy operational requirements and be sufficiently similar that a major cost difference could determine the winner.

3. Importance of Cost among Program Objectives

The contractors had good reason to believe that unit procurement cost would have an important impact on selection of a winner. Cost was a major factor among the Criteria for Evaluation and Source Selection listed in the Request for

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[1] See Aviation Week and Space Technology, March 31, 1980, page 22.

Proposal for the FY80, FY81 production buys. Operational Design/Utility was designated the most important criterion. In evaluating this criterion, equal importance was to be given to six factors:

Survivability
Operability
Accuracy and time control
Mission preparation
Life cycle cost, including cost realism
Range.

Specific Life Cycle Cost factors (not listed in order of importance) included:

Competitive program cost performance
Development and production costs
Support costs
Recurring operational costs
Unit flyaway costs
Realism of FY80/81 production program costs.[1]

Discussions at the ALCM Program Management Office (PMO) indicate that the RFP, in effect, made Life Cycle Cost the second ranking factor for the source selection. Also, in 1979 Rear Admiral Walter M. Locke, Director of JCMPO, warned that: "...cost per unit will be one of the sensitive items."[2]

4. Validation of Cost Estimates

The Air Force was in a good position to validate unit cost estimates, since the FSED prototypes were considered preproduction prototypes and could be expected to require only

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[1]See Request for Proposal for FY80/81 Production, N00019-79-R-1000, December 22, 1978, page 67.

[2]See Aviation Week and Space Technology, April 2, 1979, page 67.

minor design changes following the competitive testing.[1] And, as mentioned above, the competition included pilot production of 24 missiles by each competitor to demonstrate production capabilities and provide additional information on production methods and costs. Even though the first pilot production delivery did not occur until after the March 1980 source selection, the pilot production effort was in progress during the competition and provided valuable information during four production readiness reviews. Design-to-cost reviews were also held and detailed cost estimates were built up based on part-by-part analyses to support the production proposals.

5. Priced Production Options

At the end of the FSED phase, the competitors were required to submit firmly priced proposals for the FY80 and FY81 production buys of 225 and 480 missiles (respectively). This amounted to 21 percent of the 3418 missiles planned at the time and would include a full year of production at the full-scale production rate of 40 per month. The proposed production contracts were required to be FPIF with nine percent profit rates, 120 percent ceilings, and 80/20 share lines. The proposals were comprehensive and included firm prices for the recurring costs of both the missiles and the associated operational support equipment. In addition, the proposals established firm ceilings for Government funding of special tools and special test equipment unique to the ALCM

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[1] Discussions at Boeing emphasized the value of FSED prototype competition for validating cost estimates. Boeing's own AD effort had emphasized performance and did not leave Boeing in a good position to estimate production costs. Further, as discussed below, the FSED prototype competition enabled Boeing to prove out a production method that the Air Force might not have accepted based on a paper proposal alone.

Program. The proposals also included a firm ceiling on the cost of developing and testing prototype depot support equipment, although production prices for such equipment were to be negotiated later.[1] Firm prices were not established for initial spares and repair parts, but the contractors were required to recommend what items in what quantities the Air Force should acquire as spares and what items should be planned for depot repair. The best and final offers (BAFOs) for the production proposals were required by October 1979, midway through the test flight program. This meant that the contractors would have some flight experience to bolster their confidence in their own estimates and perhaps increase their willingness to bid low. But one competitor would not yet know whether the other competitor was going to suffer serious technical failures[2] that would, in effect, leave the first competitor in a sole-source bidding position.[3]

6. Competition during Follow-on Procurement

The RFP required the competitors to propose and price options for implementing leader/follower arrangements for later ALCM production. Each competitor would offer to be a

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[1]The contractors were required to propose what hardware items would be required to perform the tasks specified by the Air Force. The winning contractor would bear the cost of developing any additional items discovered to be necessary to perform the same specified tasks. At the time of the proposals, the maintenance concepts were on paper but the hardware had not been designed.

[2]While test data were not shared between the contractors during the flyoff, there is no assurance that major failures would remain secret. For example, test flight crashes (each competitor sufferred four) were reported in the press during the flyoff. See Aviation Week and Space Technology, December 3, 1979, page 22.

[3]Based on discussions at the ALCM PMO.

leader, which would include staging a competitive selection of a follower contractor and transferring the data, tooling, test equipment, and personnel necessary to enable the follower to produce the ALCM. An award fee would be attached to successful performance of the leader role. After a start-up period, the follower would compete with the leader for some portion of future ALCM procurement. While the leader/follower option was never actually exercised, the BAFOs included priced options, and both the contractors and the JCMPO had every reason to expect that they would be exercised.[1] At the time of the flyoff decision, the Air Force expected a decision on the leader/follower option at or soon after the forthcoming DSARC. The option would be exercised for FY83, with a 60/40 split.[2] A similar leader/follower arrangement has been implemented for production of the Tomahawk for its SLCM role.

7. Correction of Design Deficiencies

The contractors were required to include an availability guarantee in their FY80/FY81 production proposals. Under this guarantee, the contractor was required to correct problems that prevented production missiles from achieving a specified standard of availability based on ground tests. A firm

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[1]Based on discussions at the ALCM PMO. Discussions at Boeing also indicate that Boeing took the possibility seriously, and made an organized effort to understand how leader/follower would work. Nevertheless, Boeing based its production planning and investment on the full rate of 40 per month. (In April 1980, the DSARC 3 that approved full-scale production decided against implementing the leader/follower option. Boeing's final go ahead for its new plant investment also occurred in April 1980.) The discussions also emphasized the difficulties of introducing production competition when program quantities are unstable and when the technical data package is based on the leader company's methods and resources.

[2]See Aviation Week and Space Technology, March 31, 1980, page 18.

ceiling was established for Government funding of such corrections. In addition, a $2 million award fee was available if the number of failures during operational test flights could be held below a very tight standard.

8. Summary of Competitive Incentives

In summary, the ALCM competition was structured in such a way that it could be expected to put considerable pressure on unit procurement cost. If the competitors wanted to win--and the prize was substantial--they would have to react to the ranking of cost as the second most important item among the source selection factors. Cost would almost surely come into play since both competitors had good predecessor missiles and probably would be able to satisfy operational requirements. Further, DoD had mechanisms in place to transform optimistic cost estimates into lower actual costs. The competitors were required to make firm price offers for the FY80, FY81 buys before a winner was selected. The pilot production programs provided DoD with good information from which to estimate production costs and hence what would happen to prices following the FY81 buy. Arrangements for a leader/follower program to establish procurement competition during those later years promised to limit a contractor's ability to recoup any FY80, FY81 losses. This would increase pressure on the contractors to bring down production costs rather than just their initial prices. Finally, an availability guarantee was required in order to balance the strong emphasis on production costs.

D. RESULTS OF COMPETITIVE FULL-SCALE DEVELOPMENT

1. Source Selection

In March 1980, Boeing was selected as winner of the full-scale development competition. ALCM production was approved by DSARC 2 in April and the production contract for the FY80 buy of 225 ALCMs was awarded in May (as indicated on Table D-3) with an option for the FY81 buy of 480 missiles. The program also included continued flight testing, engineering development (especially for depot support equipment) and logistics support.

The Source Selection Decision Document explained that Boeing's selection was due to superiority of its missile in meeting the specified operational requirements and goals for performance, mission preparation and supportability and to superiority with regard to the adequacy and completeness of its program for remaining development, production and deployment. Specifically, Boeing's guidance software provided a significantly superior terrain-following capability, a greater potential for meeting accuracy requirements, and easier mission planning. The aerodynamic qualities of the missile itself also gave it superior rough-terrain-following characteristics. Also cited as superior were the Boeing missile's maintainability, the quality and technical excellence of its design, and Boeing's configuration management.

The Secretary of the Air Force commented that the guidance software "may have been the dominant factor in the

Table D-3. CHRONOLOGY FOR ALCM PRODUCTION PERIOD

DATE	EVENT
March 1980	Boeing selected as winner of full-scale development competition.
April 1980	DSARC III approves ALCM production.
May 1980	FY80 production contract awarded to Boeing.
December 1980	FY81 production contract awarded to Boeing.
September 1981	First Alert Status achieved with deployment of B-52 with 12 pilot production ALCMs.
November 1981	First missile from FY80 buy rolls out of new Boeing factory.
Late 1982	Negotiations for FY82 buy.

decision."[1] He also praised both competitors and noted that the differences in their offerings were small but significant. He noted that:

> The cost differences between the two bidders were not significant. Boeing has won clearly and cleanly...[2]

Boeing's ALCM program manager gave partial credit (for winning) to an aggressive test program which identified problems early and allowed Boeing to demonstrate the soundness of its missile's design in "go-to-war" missions.[3] He also cited efforts made by Boeing to reduce production costs.

The Source Selection Advisory Council (which included six Air Force generals and six Navy admirals) voted 12 to zero in Boeing's favor.[4] It was noted that Boeing's missile had "passed all of the specification requirements with little or no reservations."[5] While each contractor experienced four crashes (out of ten test flights), this was considered normal and the test program was viewed as worthwhile and influential to the selection.[6] The tests demonstrated that the Boeing missile was basically ready for production although DoD did

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[1]See Aviation Week and Space Technology, March 31, 1980, page 18.

[2]See Armed Forces Journal International, May 1980, page 17.

[3]See Aviation Week and Space Technology, March 31, 1980, page 18.

[4]Ibid., June 16, 1980, page 177.

[5]Ibid., June 16, 1980, page 179.

[6]Ibid., March 31, 1980, page 18.

direct three changes involving Government-furnished equipment and some minor producibility changes.[1]

In summary, Boeing's insistence on doing its own guidance software (rather than accepting the McDonnell Douglas software) gave it an opportunity to differentiate its product in a way that may have been decisive. Boeing was have gained a support cost advantage through planned commonality with the SRAM maintenance program (since Boeing had been prime contractor on the SRAM program). Also, the superiority of Boeing's production and deployment program was important because of the urgency of the ALCM production requirement. Finally, it should be noted that the benefit of the competition is not just that Boeing's entry was superior to General Dynamics', but that both programs were superior to what would have been offered on a sole-source basis.

2. Design Changes to Reduce Unit Cost

The ALCM Program provides an example of the application of R&D competition just in time to influence the process of transitioning the design into production. While producibility engineering and production planning and learning would have occurred without competition, the need to propose and then live up to competitive prices for the FY80 and FY81 production contracts motivated an especially intense and successful cost control effort.

The ALCMs developed by Boeing and General Dynamics for the FSED competition were aerodynamically similar to and had high degrees of parts commonality with their respective advanced development cruise missiles. However, both were

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[1]Ibid., May 12, 1980, page 44.

longer than their predecessors in order to carry more fuel for greater range.[1] The Tomahawk was increased from 218 to 240 inches while Boeing's ALCM was lengthened from 168 to 249 inches.[2] Boeing also redesigned its missile's nose and tail and increased its depth in order to improve operational characteristics and increase fuel capacity. These changes were possible because the missiles were no longer constrained to fit the SRAM rotary launcher. As noted above, the competitors were expected to design new internal (to the B-52) launchers to accommodate their ALCM entries. The engine and guidance hardware remained basically the same for both entries.

With the onset of competition, Boeing established a special producibility task force to identify design changes to reduce production costs, and claimed to have reduced missile unit costs by 30 percent.[3] The emphasis was on changes that would reduce costs without affecting performance. Unit costs had received some consideration when the original FSED designs were established, but the emphasis had been on achieving the required performance.[4] Boeing conducted 92 preproduction design-to-cost studies and incorporated 54 of the proposed

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[1]Range was set at 2500 km (1553 miles) in anticipation of a SALT limitation that never occurred.

[2]The previous Boeing extended range version was to be 228 inches long and had largely been designed prior to the competition.

[3]See Aviation Week and Space Technology, April 2, 1979, page 67.

[4]As noted above, the Air Force had encouraged design flexibility by specifying both goals and minimum acceptable levels for certain system characteristics. Discussions at Boeing indicate that for nine such characteristics, the goals were achieved in three cases, the minimum requirement was exceeded in five more cases, and the minimum was achieved in the remaining case.

changes, for an average savings per air vehicle estimated at $94,938 (in constant FY77 dollars) per unit. Some of the major changes identified prior to the March 1980 source selection include:[1]

- Change fuel tank construction from welding 28 machined forgings to bolting four cast sections for a savings of $29,457 per unit (this change is discussed at length below);
- For the boattail and aft body, change from forged block and/or build-up designs to castings and/or die forgings for a savings of $10,423 per unit;
- For the engine inlet, change from a fiberglass and sheet metal construction to a machined sand casting for a savings of $2,774 per unit; and
- For the elevons and fin, change from machined aluminum to molded graphite epoxy for a savings of $2,718 per unit.[2]

A number of other major producibility design changes were identified only after Boeing had won the FY80 production contract:

- Eliminate fuel system vacuum loading and fuel pressure indicating system for a savings of $3,226 per unit;
- Replace faying surface tin plating with conductive alodine for a savings of $3,571 per unit;

[1]The second change listed was incorporated by the first FY80 production unit. The others were incorporated while some of the FSED prototypes were still being fabricated.

[2]Based on information provided by Boeing.

- Change elevon housing from a steel blocker forging to a titanium investment casting for a savings of \$2,307 per unit;[1]
- Change materials for the wing, fin, and elevon mechanism components for a savings of \$3,542;
- Change from nose with a cap of radar-absorbing material to a straight cast nose.[2]

In addition to design-to-cost changes such as those mentioned above, Boeing conducted 40 preproduction manufacturing-producibility studies, incorporating 25 of the ideas for a savings of \$11,086 per unit. A large number of producibility studies were also conducted at Boeing suppliers. Altogether, the preproduction studies were estimated to have saved some \$106,024 (in constant 1977 dollars), compared to a September 1982 airframe cost estimated at \$297,800 (in constant 1977 dollars). Of course, some of these changes might have been made even without competition.

As indicated above, the most dramatic of the producibility design changes was the decision to use net-shape casting for the fuel tank (which formed the greatest portion of the missile body itself). The Boeing ALCM airframe had a trapezoidal shape (as did Boeing's SRAM airframe) that tapered

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[1]Discussions at Boeing indicate that the casting change reduced machining time from 600 to 125 hours. Further efforts, including the relaxing of some tolerances, have reduced machining time to 30 hours. Weight reduction had also been a consideration in the decision to use titanium rather than steel (strength is necessary due to the dynamic loads imposed on the housing as the elevons steer the missile).

[2]By changing the shape of the nose, Boeing was able to reduce its radar signature and thus avoid the cost of the cap, machining of the nose surface to make room for the cap, and difficulties in bonding the cap to the nose surface. Since the nose change and the fuel system change mentioned above were considered by the Air Force to have affected performance, they were treated as value-engineering changes wherein the savings were shared by the Government.

down from top to bottom. Boeing preferred this shape to the rounded cross section used by General Dynamics since it made more efficient use of space when mounted on a rotary launcher in a B-52 bomb bay. During advanced development, Boeing built up the AGM-86A prototype tanks from sheet metal in a welded box construction. For the FSED prototypes, Boeing planned to construct the tank by welding together forged aluminum ring segments. Forged blocks would be machined out for the FSED prototypes, while die forgings would eventually be used for production missiles.[1] But as the missile grew to its extended-range size, the number of ring segments increased until the requirement was for circumferentially welding together 28 intricately machined forged rings. Boeing realized it would have difficulty meeting the required production schedule of two missiles per day (at a reasonable cost) because of welding problems. Welding quality requirements were particularly high because the tanks were expected to contain fuel for ten-year periods. Boeing tried to use automatic welding equipment but could still see that it would have difficulty obtaining adequate welds without considerable and costly reworking.

By the time the FSED competition was directed in September 1977, Boeing had begun to consider casting the tank. The competition made the cost and schedule risks associated with the welded-tank method untenable. By February 1978 Boeing began to coordinate drawings for cast tank segments with Alcoa's Premium Casting Division and by May 1978 Boeing had Alcoa on contract. A second casting firm, Wellman Dynamics Corporation, was placed under contract by August

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[1]The use of the welded ring construction would provide for better fuel containment and lower costs than the AD method.

1978. Cast tanks were installed on the last four FSED prototypes, three of which were flown in the competitive testing.

With the casting method, four thin-walled cast aluminum segments were bolted together and sealed to form the fuel tank. The castings were premium sand castings. They were extremely complex and included all the internal ribs and substructures. The cast segments required machining only at the external and mating surfaces and were expected to reduce machining costs by 80 percent compared with the previous method.[1] The cast method was expected to increase weight by 42 pounds and, as noted above, to reduce unit production costs by $29,457 per unit or $100 million in total (in constant 1977 dollars). But net-shape casting was a relatively new technology and had not been used before for a primary airframe structure. Boeing had gained some confidence in the method by using a large aluminum casting (made by Hitchcock) for a large structural bulkhead on the recent YC-14 development effort. The technique was difficult since cooling had to be carefully controlled and uniform structural properties had to be obtained. Alcoa had not made a casting this large and complex but had demonstrated the required capabilities (e.g., pouring techniques, thick-thin transitions). Nevertheless, the technique was considered risky and it "had to withstand opposition both within and outside" Boeing, according to Boeing's (then) chief engineer.[2] Boeing was forced to add 30 percent to the usual tank strength requirement just because it

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[1]See Aviation Week and Space Technology, March 31, 1980, page 21.

[2]Ibid., April 2, 1979, page 67.

was using a casting.[1] Boeing felt it was critically important that it demonstrate the method during the FSED flight testing so that its technical feasibility and potential unit cost savings would be credible to the Air Force, and was able to implement the method for the last four FSED prototypes.[2] In addition to some design conservatism within Boeing itself, the method was difficult for Boeing to accept because it meant reducing its share of contract costs and relying on outside firms for its airframe structure, a first for Boeing.[3]

Without competition, would the cast tank have been adopted? Discussions at Boeing suggested that Boeing would eventually have adopted casting due to the welding problems and the difficulty of meeting the schedule, but may have adopted it sooner because of the competition.[4] Discussions at the ALCM PMO questioned whether Boeing in fact would have turned to the risky new technology without the competitive necessity of bringing costs down. Further, as noted above, the casting method tended to reduce Boeing's make/buy ratio and made it dependent on outside suppliers for its airframe structure. Finally, it should be emphasized that if the competition between Boeing and General Dynamics had been decided based on paper designs rather than prototype

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[1]Discussions at Boeing indicate that this additional requirement has proven to be unnecessary.

[2]Discussions at Boeing suggest that in a paper competition, tank casting probably would not have been accepted by the Air Force. The prototype competition gave Boeing a chance to demonstrate that it worked.

[3]Under the previous method, most of the forged segments would have been fabricated by Boeing itself. Boeing lined up two suppliers for the cast segments (in part) to hedge its schedule and cost risks.

[4]That is, without competition Boeing might have initiated production with the forged-ring method and switched to casting when it appeared prudent.

demonstrations, the cast method probably would not have been accepted as credible and Boeing might well have lost.

3. Changes to Reduce Costs during Production

Boeing achieved an outstanding reduction in unit costs once production began.[1] Basic factory line (BFL) hours for the air vehicle were in excess of 10,000 hours per unit for most of the FSED prototypes. For the FY78 and FY79 pilot production prototypes, which incorporated many of the producibility changes mentioned above, BFL hours averaged 7998. For the first unit of FY80 production, BFL hours were 5669 and, following an 85 percent composite improvement curve, were expected to decline to 1500 for the 705th unit (at the end of FY81 production).[2] In fact, 1500 hours were achieved for unit number 160 in August 1982 and a composite improvement curve of 65 percent was achieved for the first 200 units. BFL hours for unit number 225 were 1310.[3] Through a continuing, intense effort, BFL hours reached 1000 in August 1983 after approximately 620 units had been produced. Further, ALCM standard hours, which indicate the theoretical number of hours that could eventually be achieved through efficient production, have declined from 1350 to 815 due to changes in work content. Yet ALCM BFL hours have reached 1.2 times the standard and Boeing has proposed to achieve 1.13 times the standard. No other Boeing program has achieved two times its (respective) standard.

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[1]Data in this section were provided by the ALCM PMO and by Boeing.

[2]With an 85 percent improvement curve, BFL hours per unit would decline by 15 percent as the quantity produced doubled.

[3]These reductions were achieved while production was being increased to its full rate of 40 per month by the end of the FY80 run.

These cost reductions were achieved through a constant series of producibility changes, 75 percent of which involved some form of design change. For example, design engineers were able to relax tolerances that originally had been set conservatively in order to assure that the prototypes would fly. In some cases, it was possible to relax testing and inspection requirements as confidence was gained in the production methods. In one instance, production testing was reduced by increasing the specified safety margin for hardness to radiation. For the most part the changes did not affect performance, although six did and were treated as value-engineering changes. Altogether, there have been at least 74 class-1 cost reduction engineering changes to tne air vehicle during the production program, and over 800 class-2 changes. Productivity changes in production have also been extensive and, in fact, led to many of the producibility design changes. For example, a tool was identified to permit simultaneous drilling of the bolt holes at the tank section joints rather than drilling them one at a time. A robot was acquired to sand the wing, reducing the required hours from 60 to 8.7 and eliminating a dreary task. Assembly tooling was redesigned to eliminate certain two-man operations. A worker discovered that a rectangular block of metal from which one part was cut could actually accommodate two such parts.

Changes such as those exemplified above were achieved through a continuing series of cost reduction measures and programs. Some of these included:

- The ALCM Bee effort begun in October 1979 resulted in implementation of 270 out of 472 ideas generated for an estimated savings of $46 million;
- Error-Free Manufacturing Planning was implemented in early 1980 and resulted in implementation of 446 out of 850 ideas generated for an estimated savings of $38 million;

- An ALCM Cost Reduction Program begun in late 1980 resulted in implementation of 124 out of 394 ideas generated for an estimated savings of $6.1 million;
- The Tiger Team Quality Circles were initiated in February 1982 to provide a forum for the productivity ideas of factory workers and have resulted in the implementation/resolution of 144 of the 165 ideas/problems identified;
- A 1982 industrial-engineering study of manufacturing methods resulted in implementation of 135 out of 188 ideas generated for an estimated savings of $1.9 million;
- The Curve Buster multidiscipline cost reduction teams were established in early 1982 to assure that the goal of 1500 BFL hours would be achieved, and resulted in the implementation of 394 out of 556 ideas generated.

Thus, the cost-reducing changes in manufacturing methods and producibility design that supported the outstanding reduction in BFL hours resulted from a concerted, relentless, multidiscipline effort initiated by Boeing management. Events such as the achievement of 1500 or 1000 BFL hours were treated as major accomplishments accompanied by motivational ceremonies. While BFL hours would have declined even without competition, the decline actually achieved was exceptional.

4. Production Facilities

To produce the ALCM, Boeing built a new production facility with a dedicated machine center, processing and fueling facilities, and assembly areas.[1] Boeing invested $50 million of its own funds in the Kent, Washington plant including $26 million for brick and mortar (covering 274,000 square feet), $9.5 million for fabrication equipment

[1] The plant can produce 40 missiles per month, largely on a single shift. Hence it has considerable surge capability.

(including 19 numerically controlled machine centers as well as conventional machines and a dedicated computer), and $12 million for processing capital equipment.

The new facilities provided a number of advantages for the ALCM Program:

- The plant was optimized specifically for ALCM production;
- Consolidation of most activities at a single location reduced interplant handling problems;
- Production equipment was state-of-the-art and highly productive;
- Fabrication equipment was dedicated to the ALCM, thus reducing schedule risks (by avoiding conflicts with other Boeing programs);
- Dedication of fabrication equipment also provided great flexibility for the continuing cost-reducing changes in ALCM manufacturing methods and producibility design.[1]

Boeing did have to take special steps to control the risks associated with starting up a new facility.

Boeing overran the $8 million contractual ceiling for Government-funded special tools and test equipment (ST/STE), spending an additional $4 million of its own funds. In some cases, originally planned tooling did not work as expected. In other cases, tooling changes were made specifically to reduce production costs or to accommodate producibility design changes. For example:

- A change from single-spindle to three-spindle machining increased tooling labor by 3,429 hours but reduced production labor by 28,313 hours;

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[1]Discussions at Boeing suggest that as much as 20 percent of the reduction in direct labor costs may have been due to the dedication of the production facility, and especially of the fabrication area, to the ALCM.

- A change from single-spindle mills to headcenter tank drilling increased tooling labor by 3,345 hours but reduced production labor by 9,246 hours;
- A change from a jig bore to a special multi-spindle wing drilling machine increased tooling labor by 1,597 hours but reduced production labor by 13,001 hours.

The decision to build a new plant with dedicated fabrication equipment was made in February 1979.[1] Previously, it had been planned to utilize general-purpose fabrication equipment already owned by Boeing at various Seattle area locations (and to subcontract for some fabrication) and to assemble the ALCM at the Boeing Development Center. The information gained through construction of the FSED prototypes and through the FY78/FY79 pilot production enabled Boeing to conduct part-by-part studies of the cost trade-offs between conventional and numerically controlled equipment and thus indicated the potential savings from a dedicated new fabrication area. In addition, the (then) planned ALCM buy of 3418 missiles seemed to satisfy Boeing's criterion of investing in dedicated facilities no more than 2.5 percent of the expected amount of business.[2] While the decision to invest in the plant and considerable planning of the plant layout had occurred before Boeing was selected, ground-breaking for the new plant did not occur until April 18, 1980, just after the source selection and DSARC production decision. The new machine shop was activated in May 1981,

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[1] This discussion is based on information provided by Boeing.

[2] In fact, the ALCM buy was recently cut to barely half of the original amount, with the last buy expected to occur in FY84. While the investment in new facilities may be nearly amortized by then, Boeing would not have made its investment based on such a small run. The general-purpose equipment can be used for other Boeing programs but new business must be found for the plant.

final assembly of the first FY80 production missile began at the new plant in September 1981 and the first missile was completed in November 1981.

The investment in a new and dedicated plant had a major impact on production costs. Prior to the competition, the plan had been to use existing plant and equipment. Discussions at Boeing indicate that a new building for ALCM assembly might have been built even without the competition, but it would not have included the dedicated fabrication area that was so important to achieving the production cost reductions. It is unusual at Boeing for a program to be provided with both.

5. Subcontractors

Subcontractors accounted for 55 percent of Boeing's production costs for the FY80, FY81, and FY82 buys. Casting of the fuel tank segments accounts for an important share of subcontractor costs. There are now three subcontractors for sections 1 and 2 of the fuel tank. Alcoa was brought on board first, with a May 1978 contract award. Wellman Dynamics was awarded a contract later in 1978. Dual-sourcing of the tank castings provided Boeing with a means of hedging development and production schedule risks as well as motivating cost control through price competition.[1] Alcoa committed to a second production facility (requiring another set of tooling) for tank segments 1 and 2 at El Paso, and began production there in April 1983. In part because Wellman alone could not have produced all of the requirements for the difficult 1 and 2 segments, Boeing is bringing in Hitchcock Industries as a

[1]The most recent split-award competition drastically altered the allocation of production between Alcoa and Wellman.

third supplier, with a contract awarded on September 2, 1982 and with production scheduled to begin this year (1983).[1]

Producing tank segments for the ALCM required some capital investment by the subcontractors, in addition to the tooling funded by Boeing. Further, meeting the stringent quality requirements for the difficult and complex castings forced the subcontractors to allocate some of their best resources (e.g., skilled workers, sophisticated equipment) to the effort. Some problems in meeting required deliveries developed in late 1981 due to the disrupting effects of reworking casting defects, but these problems have now been resolved.

6. Cost Growth for the ALCM

Estimated unit procurement cost (UPC) for the ALCM increased from $675 thousand in January 1977 to $1.021 million in December 1982 (in constant 1977 dollars). However, this increase includes the unexpected reduction in the planned buy from 3418 to 1523 units.[2] Thus, the cost growth is largely due to the spreading of fixed costs over a smaller quantity than was intended. UPC in September 1982 (prior to the reduction in quantity) was estimated at $769 thousand (in constant 1977 dollars) for an increase of 13.9 percent over the January 1977 estimate. Since the UPC for the median noncompetitive program discussed in Chapter III would have

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[1]The decision was made and tooling funds were arranged before the recent truncation of the ALCM Program.

[2]The December 1982 SAR indicates procurement of 1523 units ending with the FY83 buy. It was subsequently determined to procure 240 units in FY84 as well. The truncation of the program is reportedly due to a decision to develop an advanced ALCM using "stealth" technology. See National Journal, March 26, 1983, page 644.

increased 34.8 percent over a comparable period, it is apparent that UPC control in the ALCM Program has been effective. It is also clear that a substantial portion of the UPC savings generated by the ALCM competition will not be realized due to the elimination of ALCM production after the FY84 buy.[1] As noted above, the FSED competition was expected to cost $313.5 million for Boeing and $201.2 million for General Dynamic's R&D contracts plus $95.8 million apiece for pilot production. Thus, a reasonable estimate of the incremental cost of holding the competition would be the average of these amounts per contractor, or $353.2 million.[2] Using the September 1982 estimates (i.e., before planned production was cut), the savings resulting from lower UPC growth would have amounted to $1,231.0 million or 3.5 times the incremental cost of the competition.[3] In constant dollars (eliminating the distortion that results when escalated savings dollars have sufferred much more from inflation than the original costs of the competition), the ratio of estimated savings to incremental cost is still 2.0. And if the constant-dollar savings and costs are discounted to take into account the fact that the costs of competition are incurred up front while the potential savings are realized only in the future (as discussed in Chapter V of the main report), the

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[1]The Government's investment in R&D prototype competition, like Boeing's investment in plant and equipment, was made in the face of some risk of program reduction or cancellation.

[2]This estimate is somewhat conservative in that it does not reflect the value of what was salvaged from General Dynamic's pilot production to be used in the Tomahawk Program (e.g., engines, guidance hardware).

[3]Based on the December 1982 procurement cost estimates, the savings amounts to $482.9 million or 1.4 times the incremental cost. But in constant, discounted dollars (as discussed in the text), estimated savings are less than the incremental cost of holding the competition.

ratio is still 1.2. Thus, if the lower UPC growth rate for the ALCM can be attributed to the FSED competition, it is apparent that the savings would have more than compensated for the incremental costs of holding the competition (if the production program had not been truncated).

Clearly, the price ceilings in the production options had a considerable influence in motivating Boeing to control its costs. The Government's costs for the competitively priced production contracts for FY80 and FY81 are expected to be at or near the ceiling prices, despite Boeing's tremendous effort to control and reduce production costs.[1] This suggests that the competitive bidding forced the proposed prices down, which in turn motivated the continuing cost control effort. The results of the sole-source negotiation of the FY82 buy also indicate that the FY80 and FY81 prices were held down by competition. The FY80 proposal had assumed that a particular measure of labor hours would average 1700 while the FY81 proposal assumed an average of 1200 hours. The FY82 negotiations seemingly indicated that the improvement curve had flattened out, since the average that was negotiated for this measure of labor hours was 1250. The Air Force's negotiating position had been that the improvement in hours would continue and, in retrospect, the Air Force was correct.[2] However, while Boeing bid more conservatively in a sole-source environment, the Air Force's position in the FY82 negotiations was strengthened by the fact that when they took place in the second half of 1982, information on actual

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[1]Discussions at Boeing indicate that, at one point, Boeing expected its FY81 costs to be $25 million over the ceiling but has since been able to reduce costs to or slightly below the ceiling.

[2]Based on discussions at the ALCM PMO.

production costs was already available for at least half of the FY80 missiles. Thus, Boeing had already demonstrated its prodigious ability to reduce labor hours, reinforcing the credibility of the Air Force's position. The FSED competition affected the FY82 negotiations in another way as well. Boeing had established a solid baseline cost estimate to support its competitive production proposal, 85 percent of which was based on labor standards for individual parts. This provided substantial help to the Air Force in supporting its position.[1]

In addition to competition's impact on unit procurement costs, it had other beneficial results. Boeing was successful in meeting the production build-up to the full rate of 40 per month within one year. This was an important and difficult requirement and the ability to meet it received consideration during the flyoff source selection. Further, the competition provided better ALCM design and performance, Boeing's superior terrain-following capability being a noteworthy example. Also, Boeing and General Dynamics exhibited relatively good control of R&D costs during the competition.

E. CONCLUSIONS

The ALCM competition was timed and structured so as to place major emphasis on the control of unit costs as the ALCM design was transitioned into production, and that is what occurred. Competition was introduced at a time when many of the performance issues had been resolved, based on the flight tests during the advanced development (AD) programs of the ALCM and the Tomahawk. The flight tests at the end of the

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[1]Based on discussions at the ALCM PMO. How much this information helped cannot be known, but Boeing's initial offer was certainly higher than its final offer.

competitive full-scale engineering development (FSED) program confirmed that the FSED designs were mature and ready for production. Thus, the competition was introduced just when the designs were ready f.. producibility design changes to permit efficient production and just as production methods themselves were being planned and as decisions on capital invest.ent were being considered.

The competition was structured to include pilot production of 24 missiles by each contractor. This provided the contractors an opportunity to demonstrate to the Air Force that planned production methods and producibility design changes would actually work and would achieve the cost savings anticipated. Also, the requirement for competitively priced production options and the prospective importance of unit costs in the source selection provided a strong motivation to the contractors to identify such savings.

In fact, Boeing wa able to identify important cost-reducing design changes before it won the competition as well as after it had been selected but before FY80 production units were delivered. Producibility design changes and improvements in production methods continued throughout the FY80 and FY81 production contracts. Production cost savings can also be attributed to Boeing's decision to invest in an efficient, state-of-the-art plant, tailored and dedicated to ALCM production. The provision of dedicated fabrication equipment was particularly useful in providing flexibilty for the continuous stream of cost-reducing changes. Maintenance of dual production sources for the main cast segments for the missile body also contributed to the control of unit costs.

Prior to the decision to cancel future ALCM production (after FY84), it appeared as though savings in procurement cost growth would more than offset the incremental cost of the

ALCM competition, even when the comparison was based on constant, discounted dollars. The margin, however, was relatively close due to the great expense of a substantial FSED program with pilot production. After the cancellation, the savings will accrue over fewer missiles and will evidently not offset the incremental cost of the competition (on a constant-dollar, discounted basis). This exemplifies that the Government's investment in prototype competition, like Boeing's investment in a new production plant, does carry certain risks.