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'DESIGN TO COST' - PROBLEM DEFINITION, SURVEY OF POTENTIAL ACTIONS AND OBSERVATIONS ON LIMITATIONS

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Arlington, Virginia

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13. ABSTRACT

This paper provides a framework for discussion of the "Design to Cost" concept from the viewpoint of cost analysis. "Design to Cost" is viewed as a concept involving the design of a weapon system, using "cost" as a key design parameter. The "Design-to-Cost" literature often includes a variety of actions of broader scope, and these are noted in an effort to place "Design to Cost" in a proper context. Potential actions which DOD might take to achieve "Design-to-Cost" goals are discussed. (A survey of actual actions being implemented by DOD is not made.) Finally, observations are made concerning several problems that may limit the achievement of the "Design-to-Cost" goals.

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FOREWORD

This paper was presented by invitation of the co-chairman at the 30th MORS meeting, Working Group B-4, "Costing". The co-chairmen were Mr. Alan D. Yaross, USAF/Aeronautical Systems Division, and Mr. Jack Hockett, MITRE Corporation. The MORS meeting was held at Fort Lee, Virginia, December 12-14, 1972.

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I. INTRODUCTION

The DOD is in serious budgetary trouble. Externally, critics of the Defense Department are demanding that the Defense budget be reduced by applying the "peace dividend" to nondefense areas. Further, pressures to hold down total government spending make DOD a prime target for cuts. Internally, the actual costs of weapon systems seem more expensive than ever, and we have not yet solved the problem of cost overruns which so plague our planning and programming of forces. Further, the need to replace aging weapon systems, long deferred because of the Vietnam War, is becoming more critical every day. It is obvious that DOD must find ways not only to control cost overruns so that its planning will be more orderly, but also to reduce the actual costs of its weapon systems if we are to have viable forces within the foreseeable budget ceilings.

Under the leadership of Secretary Packard and Dr. John S. Foster, Jr., Director of Defense Research and Engineering, DOD has initiated a number of actions aimed at reducing costs. Many of these actions are covered under the concept of "Design to Cost". I will try to provide an overview of the concept from the viewpoint of cost analysis. My primary objective is to provide a framework for discussion. Some of the material presented here may be controversial but it should be understood that these views do not necessarily represent the official government position.

The discussion is divided into three parts. The first part is an attempt to define the phrase "Design to Cost". There are at least three concepts of "Design to Cost", encompassing descending levels of aggregation. The second part of the paper lists potential actions that might be taken to achieve the goals of "Design to Cost". There are numerous lists of possible actions, each somewhat different than the others, and they have been synthesized here for the reader's consideration. Since this paper is intended as a "think piece", no attempt has been made to survey actions actually in the process of being implemented. The third part of the paper is drawn from personal experience and is a discussion of four broad problems that may limit the achievement of "Design-to-Cost" goals.

As is the case with most "overview" papers, I shall only touch lightly on many topics which deserve far more thorough discussion.

II. PROBLEM DEFINITION

The phrase "Design to Cost" has been appearing in the DOD literature since at least 1969.* It is not clear who originated the concept, but Dr. John S. Foster, Jr., Director of Defense Research and Engineering, has been its leading spokesman and proponent. The literature is very general in nature, and contains no "authorized" specific definition. Discussions with analysts in government and industry have produced a number of interpretations of the meaning of "Design to Cost". Three of them are discussed below.

First, most analysts and most of the literature references, focus on "Design to Cost" as it relates to the <u>total weapon system</u>. Second, observations of actual practices relating to RFPs and contracts suggests a focus on <u>production hardware</u>. Third, several important references focus on the <u>total force structure</u>.

The majority viewpoint appears to have its basis in DOD Directive 5000.1, Acquisition of Major Defense Systems, July 13, 1971. The Directive states that:

> Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into "design to" requirements. System development shall be continuously evaluated against these requirements with the same rigor as that applied to technical requirements. Practical tradeoffs shall be made between system capability, cost and schedule.

The phrase "Design to a Price" is sometimes substituted for "Design to Cost". For example, Dr. Foster, in accepting the annual

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* The earliest reference in my files is dated June 18, 1969.

James Forrestal award on March 12, 1970, warned the National Security Industrial Association (NSIA) that:

> We shall insist relentlessly--as a point without peer in our management--that price has as much priority as performance. This does not rule out vigorous pursuit of new technology where that technology is required or can pay its way. And frequently, new technology can be used to reduce costs. Yet we must design-to-a-price, a much lower price, or else we will not be able to afford what we need. Defense budgets are going down. The costs of what we need, just our essential needs, are going up. Our only solution is to make cost a principal design parameter. That is how we must now define what is "best". We have no other choice.

In response to that address, the NSIA Research and Engineering Advisory Committee completed a study on "Design to a Price" in June 1972 [1]. In that study, "price" was defined as "total life cycle cost".

In other words, the "Design to a Cost (or Price)" concept is one that involves those actions which may be taken during the design phase of a weapon system using life-cycle costs as a key design parameter.

Another, more limited, view of "Design to Cost" is contained in the few RFPs and contracts released which actually address this issue. That is, although we may aspire to have total life-cycle costs as a design parameter, current actual practice seems to focus on the cost of production hardware. For example, the AX aircraft RFP, dated 7 May 1970, has a design goal of $1.4 million in 1970 dollars for a production of 600 aircraft at a peak production rate of 20 aircraft per month. The Advanced Medium-Sized Transport (AMST) contracts awarded to Boeing and McDonnell-Douglas in November 1972 have a design goal of $5.0 million in 1972 dollars for the 300th aircraft of a 300-aircraft total buy. The shift from life-cycle costs to production costs is, no doubt, just a practical one which reflects such factors as our poor data collection systems for operating costs, the inadequacy of feedback mechanisms from the field to designers, and the lack of contractual procedures for enforcing operating cost specifications.

A third view of "Design to Cost" is a much broader concept which, essentially, involves all actions that may be taken to achieve a viable force structure within foreseeable budgetary limitations. This third "macro" viewpoint represents my own interpretation of papers by DDR&E spokesmen such as Dr. Foster, Dr. Fubini, and Mr. Sullivan. For example, Mr. L. Sullivan, Jr., Principal Deputy Director, Defense Research and Engineering, addressed this concept on 16 August 1972 in a speech to the AFMA/NSIA Symposium. In brief, Mr. Sullivan observed that the purchasing power of the DOD budget will be relatively constant for the foreseeable future and that we will be unable to modernize our forces at their present levels if we continue to buy high cost weapon systems. The problem then is to "Design (a total force) to a Cost". One of his chief recommendations was to consider the overall concept of a "Hi-Lo Force Mix" to accommodate both budgetary limitations and dwindling technological superiority. I'll expand on this concept later in the paper but, briefly, this mixed force would contain a smaller, high-technology force to meet similar threats and a larger, standard force of lower-cost weapons. His recommendations also touched upon O&M Costs, Training Costs, Base Support Costs, and Manpower Allocations.

This third view has been included deliberately in order to better clarify the concept of "Design to Cost". The literature often commingles proposed actions to implement these "micro and macro" concepts, if not the concepts themselves. That is, actions which go beyond what an industrial designer can do to influence costs are often included in papers addressing the "Design-to-Cost" issue.

It is possible to interpret this third concept so broadly that one could cover any action within DOD intended to reduce costs. However, because ideas under the "Design-to-Cost" label have emanated from DDR&E, I will limit my interpretation to those actions which may be taken during the weapon system acquisition process (R&D and production).

Conceptually, then, we may wish to distinguish among the following classes of actions designed to reduce cost, and to decide which one(s) should carry the label "Design to Cost":

- Those actions which a designer may take to reduce the production costs of a single weapon system;
- Those actions which a designer may take to reduce the life-cycle costs of a single weapon system;
- Those actions which DOD may take during the acquisition process to reduce the costs of weapon systems for a mixed total force structure.

A fourth category not discussed here would cover those other actions which DOD may take to reduce the total cost of the DOD budget, including actions to reduce support costs, such as logistics, medical, training and base operating support, and headquarters and command structure costs.

III. POTENTIAL ACTIONS TO ACHIEVE "DESIGN-TO-COST" GOALS

The "Design-to-Cost" concept, however defined, appears to have emanated from DDR&E. This fact has influenced the survey of potential actions which DOD may take to achieve "Design-to-Cost" goals in two ways. First, the literature survey and personal contacts were limited to DDR&E and closely allied organizations.* Second, as previously noted, consideration of potential actions were limited to those within the direct purview of DDR&E, namely, the weapon system acquisition process (R&D and production).

Many proposed actions of varying degrees of cost impact were noted. Figure 1 lists those most frequently mentioned, plus a few that I have added. The list is not complete, but it will suffice for discussion purposes. The list arbitrarily has been divided into five areas for discussion purposes, i.e.,

(1) Design Mixed Forces to include low-cost systems;

(2) Restrain "Requirements" Growth to limit high-technology (i.e., high-cost) systems development;

(3) "Design to a Price" to keep lower-technology systems low cost;

(4) Standardize Components to take advantage of extended production runs;

(5) Increase Reliability and Maintainability to decrease life-cycle costs.

---

* For example, the Defense Science Board Task Force on Avionics, Dr. Eugene Fubini, Chairman; the Defense Science Board Cost Reduction Task Force, Mr. J. Fred Bucy, Chairman; and members of IDA's top management who are working closely with these panels and with DDR&E's management. I am particularly appreciative of suggestions from IDA's President, Dr. A.H. Flax, and from Dr. D.C. Dacy, Dr. R.H. Fox, Mr. S.J. Deitchman, and the entire staff of the Cost Analysis Group.

Figure 1. SOME POTENTIAL ACTIONS TO ACHIEVE "DESIGN-TO-COST" GOALS

DESIGN MIXED FORCES

- Buy "Hi-Lo" Mix
- Buy Functionally Specialized Equipment
- Fine Tune Threat Assessment
- Improve War Gaming Models
- Improve Force Costing Models

RESTRAIN "REQUIREMENTS" GROWTH

- Limit Introduction of New Technology
  - Avoid "Price of Entry"
  - Avoid Cost Overruns
- Tightly Manage New Technology
  - Tailor Contract to Degree of Risk
  - Use Competitive Prototypes
  - Continue DSARC Milestone Monitoring
  - Conduct OT&E

DESIGN TO A PRICE

Government

- Set Target Price
- Issue Functional Design Specs
- Relax Specs on "Mil Standards"
- Provide Contract Incentives

Contractor

- Conduct Trade-Off Analyses
- Introduce New Technology to Meet Design Specs Within Cost
- Introduce New Manufacturing Techniques to Reduce Cost

STANDARDIZE COMPONENTS

INCREASE RELIABILITY AND MAINTAINABILITY

- Set Realistic Specifications
- Improve Reporting and Feedback Systems
- Establish Warranties or Other Incentives to Meet Specs

Under each of these major actions are a number of subactions which can be taken and which are discussed later. The categories are quite arbitrary, as there seem to be a number of ways to list these actions.

A. DESIGN MIXED FORCES

One obvious action to achieve a "Design-to-Cost" total force structure would be to substitute low-cost systems for high-cost systems. Several approaches can be taken to achieve this goal. One is the deliberate design of a so-called "Hi-Lo" force mix. Another is the substitution of lower-cost systems in special situations. These approaches are discussed below followed by a discussion of some problems relating to threat assessment, war gaming models, and force costing models.

1. Buy "Hi-Lo" Force Mix

Mr. Leonard Sullivan's paper of 16 August [2] dealt extensively with the problem of providing sufficient numerical forces in the future, given a relatively fixed (in terms of purchasing power) DOD budget. One of the major recommendations which he made was that of "Hi-Lo" force mix. He described the concept as follows:

> Another alternative is to expand and formalize the concept of a mixed force, which we have termed a high-low force mix. Under this notion we would consciously project a smaller high performance force, combined with a larger standard force designed for lower total cost. In the high performance force, we would seek technological superiority in a single mission. We would tend to design the item against the worst threat it would probably face and try to achieve a high readiness and mobility for this force. . . . In the standard force, we would try to stress multi-purpose characteristics, where desirable. The system would be designed against the largest numerical threat, assuming that the higher performance forces could be made available to combat superior threat.

He continues:

> In fact, our present forces generally represent a "high-low" force mix of sorts, with higher performance in the newer machines and larger numbers of the older, poorer-performing machines awaiting replacement. The difference here would be a plan to replace some high-performance machines with better ones, and to replace others with cheaper ones. Variations in programmed mixes could then reflect annual defense budget variations.

2. <u>Buy Functionally Specialized Equipment</u>

There are some interesting possibilities for reducing costs under the mixed-force concept, a few of which follow. First, the use of functionally specialized equipment can limit the number of high-cost items which must be procured. For example, reconnaissance aircraft might be equipped with pods containing limited utility sensors, instead of being fully equipped with expensive general utility equipment. As another example, only a few aircraft in a squadron would have to be equipped with laser designators, allowing them to "illuminate" targets for the remaining aircraft. Likewise, only a few "Pathfinder" aircraft in a squadron need be equipped with expensive, highly accurate navigation equipment. Second, the widespread use of Remotely Piloted Vehicles (RPV) as a supplement to manned aircraft might save substantial sums. For example, the use of low-cost RPVs, equipped with television guidance and smart bombs, could, in conjunction with other sensing and navigation aids, essentially eliminate the need for manned aircraft in many tactical situations.

In my opinion, three actions need to be taken to implement a mixed-force concept.

The first is an improved threat assessment. That is, if we deliberately are going to procure a standardized low-cost force, we must make a realistic assessment of the threat to be certain that we are designing our forces to match the threat. There may be a military disaster if we underestimate the threat in particular areas of technology and do not have the "high-cost" forces to respond to that threat. Conversely, our total budget is such that we cannot afford to overestimate the threat and attempt to buy too much "high-cost" force. Realistic threat assessment should not be used as a means to rationalize a smaller force. We have already revised our assessment of the threat from a "2½-War Strategy" to a "1½-War Strategy" [3]. What is needed is a "fine-tuning" of the threat assessment. For an extensive discussion, see Reference [4].

Second, we must develop better techniques to analyze General Purpose Forces. Especially needed are tactical war gaming models for optimizing force mixes and force levels. Operations research analysts are well aware of the great difficulties of modeling and analyzing tactical war forces, yet the bulk of the proposed "low-cost" forces would be tactical weapons. If we are to achieve the right weapons and the right force mix, we must sharpen our analytical tools.

Third, we need improved force structure cost models so that we can better measure both the cost and effectiveness of our projected forces as we seek to achieve a better balance of forces. Force structure cost models have been under development for years, and I believe that the problem is not one of model structure but rather is one of data. We need much better cost data if the models are to be useful. For example, one great need is a better understanding of how support costs vary with changes in force structure, particularly if there are dramatic changes in either force size or force mix.

B. RESTRAIN "REQUIREMENTS" GROWTH

Mr. Sullivan suggested another alternative for lowering weapon system costs. He recommended that we restrain the continuously expanding requirements as a means of arresting cost growth. He noted that increased range, speed, thrust, payload, and avionics capability are the largest sources of aircraft and missile cost growth. As to cost growth, Dr. Flax, in an unpublished paper on "Cost and Economic Factors in Aerospace System Development", has discussed the "price of entry" that must be paid for each successive generation of technology.

For typical combat aircraft used by the U.S. Armed Forces since the First World War, he plotted the unit costs against the year in which the aircraft was introduced into operational units. The results are shown in Figure 2. Generally, lines of development have diverged as aircraft have grown more complex and expensive, with some aircraft representing a class of heavier, longer-range, higher-powered and more elaborately equipped weapon systems, while, in parallel, lighter, shorter-range, simpler aircraft of lower cost have also been developed. Dr. Flax noted that, on the average, costs for the heavier, more-complex class of combat aircraft have increased by a factor of 10 about every 18 years. Although some of this increase is attributable to inflation, he noted,

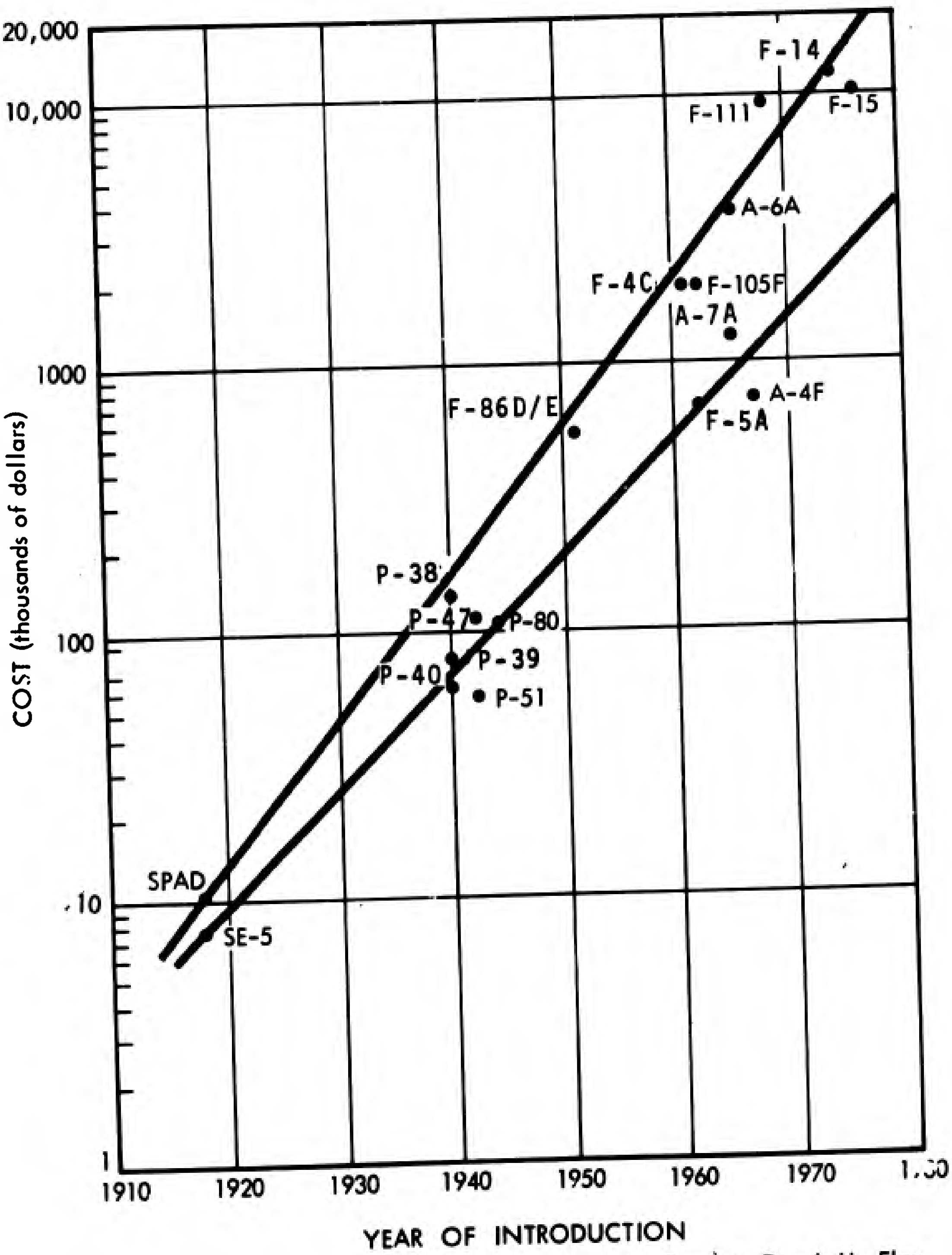
> . . . most of the increase is attributable to increasing technological complexity in airframe, engines, accessories, and avionics; by increases in size and weight and by more costly materials, processes and fabrication techniques. There have, of course, been corresponding increases in performance, speed, range, load-carrying capability and also increases in military mission capabilities such as accuracy of navigation and precision of weapon delivery.

Further, he notes that the quickening pace of technology in airframes, engines, and avionics has led to ever more frequent and expensive requirements to pay the "price of entry" into new materials, processes, design approaches, manufacturing methods, and operational techniques.

Note that not only is new technology expensive, but it is the primary source of our cost overrun problem.* It is a very difficult problem indeed, because we often develop a very carefully programmed mix of forces, given an assumption as to their costs, only to discover that certain weapon systems will cost far more. This, then, requires a painful reassessment of the situation, given today's

---

* I have deliberately used the phrase "cost overrun" even though I realize that the preferred DOD phrase is "cost growth". (See the December 7, 1969, edition of the Washington Post for an interesting discussion of a November 26, 1969, memo from Secretary Packard which proposes that "cost growth" be substituted wherever "cost overrun" is used because the latter term "creates confusion in the minds of many" and "casts improper reflection on the true status of events.")



Source: Dr. A.H Flax

Figure 2. COST OF COMBAT AIRCRAFT, 1910-1980

relatively fixed budget. This trend, if continued, can destroy plans for carefully balanced forces in the future.

These cost overruns have been demonstrated to be a function of the degree of technological advance sought in the development program. Robert Summers in a 1965 study examined 68 weapon systems that were developed in the late 50s and early 60s [5]. Summers compared initial cost estimates with final actual costs and found a systematic bias in which 80 percent of the estimates, after adjustments for quantities procured and price level changes, were below actual costs. His analysis concluded that a major explanatory variable was the degree of technological advance required. As shown on Table 1, we can see that, for a small technological advance, the ratio between the initial estimate and actual costs was 1.15, for a medium advance 1.39, and for a large advance this increased to 2.15 with a very large standard deviation. In other words, the larger the technological advance, the greater the disparity between initial and final estimates. Later studies by Perry and by Harman have not changed these findings [6,7].

Table 1. ADJUSTED COST FACTORS CLASSIFIED BY MAGNITUDE OF THE TECHNOLOGICAL ADVANCE SOUGHT IN THE DEVELOPMENT PROGRAM

	Technological Advance		
	Small	Medium	Large
Number of Observations	11	18	39
Mean	1.15	1.39	2.15
Standard Deviation	0.43	0.56	1.619

Source: Reference [5]

In sum then, our continuously expanding requirements for greater performance in our weapon systems is both very expensive in terms of actual cost and very troublesome because of the cost overrun problem.

To balance the record, I should note that it is possible for new technology to reduce costs. Frequently cited examples in the civilian economy are the transistor radio and electronic desk calculators. Military examples, however, are rarely cited. Military "requirements" for ever-increasing avionics capability may be one reason why avionics costs per aircraft have increased over time, rather than decreased with the reduction in the cost of avionics components. That is, as avionics packages become smaller and more capable, more "requirements" are generated to take advantage of that capability, and the final product is more expensive.

There are several actions that have been suggested to deal with the "requirements" problem. The first is to recognize the high price of entry of new technology and to introduce it only when absolutely necessary. In Sullivan's words [2], "we must avoid new requirements which are 'nice-to-have'. New technology for newness' sake has got to go by the boards."

Secondly, for those areas where we wish to introduce new technology, it is to be hoped that we can reduce cost growth by keying our development policy to the technological risk. DOD has initiated a number of actions in this regard, i.e.,

- Tailoring the type of contract to the degree of risk involved, awarding a cost-plus-incentive contract to developmental contractors where there is high risk, and awarding various types of fixed-price contracts where the risk is lower;
- The use of competitive prototypes and a "fly-before-buy" policy where appropriate. While this is a very worthwhile policy, it does not appear to be economically feasible to use this competitive policy on the most costly developments which have the highest degree of risk, such as the B-1 aircraft, the supersonic transport, or the space shuttle. However, I favor the use of prototypes even if prototype competition is not feasible;

- Monitoring of programs by major milestones, by the Defense System Acquisition Review Committee (DSARC). These milestones include " . . . the three most important transition points in its [major weapon system] life: conceptual to validation phase, validation to full-scale development phase, and full-scale development to production phase." [3] Associated with the DSARC is the review of cost proposals at each milestone by the Cost Analysis Improvement Group (CAIG);
- The operational test and evaluation of weapons before they are committed to production.* General Starbird's Test and Evaluation office in DDR&E, established as a result of the Blue Ribbon Defense Panel recommendations is now beginning to prescribe the operational tests for major weapons. I consider this area to be one of great technical challenge to DOD (that is, how does one realistically test weapons?), but one which should have a very high pay-off, particularly for tactical weapons.

I also must observe, however, that the services have been able to obtain waivers from current engineering test requirements for many key weapon systems.** Will they also be able to obtain waivers from OT&E tests?

C. "DESIGN TO A PRICE"

"Design to a Price" was earlier defined as the establishment of a fixed price for the production cost of the equipment. I wish to

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* I distinguish here between "Functional Testing" to determine how well systems meet design and performance contractual specifications and "Operational Testing". In the language of the 1 July 1970 Report to the President and the Secretary of Defense by the Blue Ribbon Defense Panel, "Operational testing, . . . , is done to determine to the extent possible whether such systems and materiel can meet operational requirements. It must provide advance knowledge as to what their capabilities and limitations will be when they are subjected to the stresses of the environment for which they were designed (usually combat). Operational testing must take into account the interface with other systems and equipment, tactics and techniques, organizational arrangements, and the human skills and frailties of the eventual users."

** A principle finding of a recent Comptroller General's Report to the Congress was the following. "Testing and evaluation procedures and associated terminology vary greatly among the services. The various test programs contained many approved deviations, substitutions, waivers, and examples of special circumstances. GAO has concluded that there is a need for better understanding of the basic principles and for better application of testing in DOD." The report notes, for example, that most, if not all, of the major weapon systems procured by the Army in recent years have been procured under a waiver of a policy requiring completion of engineering testing before production begins [8].

arbitrarily divide this topic into actions which the government might take and actions which the contractor might take.

1. Government Actions

Dr. Foster, in a speech on 5 October 1972, commented extensively on this policy [9]. He made six summary points:

> First, we will set a price-per-copy that is compatible with both the minimum required military performance and with what we can afford to pay for the number we need.
>
> Second, we will accept under that ceiling only quality products. Products that are just cheap aren't acceptable. Military needs must be met--or we will not buy the equipment.
>
> Third, we are willing to pay more in time and dollars in the R&D phase in order to assure achieving the desired unit production price and support costs.
>
> Fourth, we will be writing "functional specifications" rather than detailed design specifications. In this way, the designers will be given the flexibility to find solutions leading to low cost and high field reliability.
>
> Fifth, we--and the contractors--will acquire enough experience in the early phases to know that the desired product can be acquired for the established production price.
>
> Sixth, we will scrub the technical requirements and statement of work to reduce the number of military specifications and the Government data required.

I would like to comment briefly on some of these points.

As to "price", Dr. Foster's first point above established a rather vague criteria for establishing a price per copy. Earlier, however, he had provided more guidelines by suggesting four approaches [10]:

> 1. We could estimate the money available for a new system, divide by the estimated numbers needed, and thereby derive the total cost per copy. That is an important approach, but the techniques to do it well are not fully in hand.
>
> 2. We could relate the cost ceiling to the actual costs of related existing systems. For instance, we have put the lightweight fighter cost ceiling in between the cost of the F-5E International

Fighter and the F-15 fighter, since its performance goals fall in between those two. So we estimate what a required performance should cost and, if it appears low enough to provide adequate numbers, we can use that figure as the cost ceiling.

3. We could simply set the cost for the new system at the cost of the system it is to replace. For instance, we could peg the Agile missile cost to equal that of the present Sidewinder. With this approach, the designers are challenged to use technology to get improved performance at a reduced cost; a downward cost pressure which matches the upward push of inflation. I strongly support the thesis that technology can be harnessed to reduce costs. Look at the size and cost of your transistor radio; it's less costly than the vacuum-tube radios of 25 years ago--in spite of inflation. As we push technology to reduce unit production costs and lifetime operating costs, Research and Development expenditures may have to rise, but over the long pull total Defense expenditures will be better controlled.

4. Where it is impossible to find a formula for a realistic and logical cost ceiling for a new system, we will have to use judgment to pick a best figure and then iteratively adjust the figure as we start and test some designs.

Clearly, we have a long way to go to develop sophisticated guidelines, but we have to start somewhere.

As to points 3 and 5 of Foster's summary points on "Design to a Price", it may be difficult to acquire sufficient knowledge during the R&D phase to assure that the desired product can be acquired for the established production price. It is my hope that the R&D phase includes the full OT&E phase, where we may find out if something works in the field and not just in the company laboratory.

Points 4 and 6, regarding functional and technical specifications, are actions absolutely essential if truly low-cost systems are to be designed. Given some time for trial and error, the technical experts in DDR&E and in the Services should be able to develop procedures to write broad functional specifications. However, the matter of technical specifications is another matter. The DSB Panel on Weapon-System Simplification concluded that:

> Technical "design-to" specifications are being elaborately expanded and excessively detailed by highly specialized personnel of government laboratories [11].

In other words, we have a large bureaucracy and many legal restrictions to oversome.

The Panel noted that:

> A close relationship exists between the upper level of broad mission operating requirements and technology addressed in the Panel Report under "Continuity of Tradeoffs" and the lower level of detailed technical requirements that are firmly established in the subsystem- and component-oriented military specifications such as HIAD, MIL-F-8785 and MIL-STD-461, to name but a few. Once a conceptual design is established, rigid military specifications circumscribe the detail design and dictate the complexity of each subsystem and therefore, indirectly, the vehicle as a whole.

Further,

> Within the theme of simplification, the exquisite detail that has crept into technical requirements documents can and does significantly escalate the cost of weapon systems. As a specific example, MIL-F-8785, "Flying Qualities of Airplanes", has essentially tripled in size and detail in a span of approximately four years. While a good portion of the requirements are valid (i.e., a better knowledge of what constitutes good flying qualities, especially in dynamic responses), a far larger portion of the expansion imposes extra redundancy, unnecessarily complex fail-safe performance capabilities, and excessive demonstration requirements. This results in such features as extra hydraulic systems and oversophisticated electronic actuation and monitoring devices, all of which cause the increasing expenditure of critical engineering effort without substantially improving the system or the mission's accomplishment.

A seventh point should be added, namely, the government must provide profit incentives to reward contractors.

The NSIA report [1] recommended:

Consider large profit incentives (20-25%) during the development phase with the incentive tied to the achievement of production price and life-cycle cost factors stated in the specification. These incentives will be more than recovered during the production phase and would be a very strong motivation to industry management.

2. Contractor Actions

If the government can indeed provide functional specifications, freedom from technical requirements specifications, profit incentives, etc., then the industry design teams should have full opportunity to demonstrate what they can do to "Design to a Price". Three points are to be noted.

Conduct Trade-Off Analyses

The primary tool available to industry to develop a design to meet the "price" target is "trade-off analysis". This technique has been in existence for many years and is well understood by industry. For example, the Weapon System Effectiveness Industry Advisory Committee (WSEIAC) issued an extensive report in January 1965 [12]. Task Group IV, "Cost-Effectiveness Optimization", developed a set of basic instructions and procedures for conducting analysis for system optimization considering effectiveness, cost, and program time scale.

We will not review the principles of cost-effectiveness analysis here, but will move from this industry view of the overall design procedure at a system level to an industry example of trade-offs at the component level. The familiar "carpet plot" is often used. In a carpet plot, two design parameters are plotted in relation to one another and to cost, which is read off a third axis. An example, adapted from a Boeing Corporation chart, is displayed on Figure 3. In this instance, the man-hours per pound required to manufacture production parts at some standardized quantity, say 100, are plotted as a function of the number of equivalent hand rivets per pound and the number of parts per pound. For example, a design which had two parts and 30 rivets per pound would require about 2.5 manufacturing

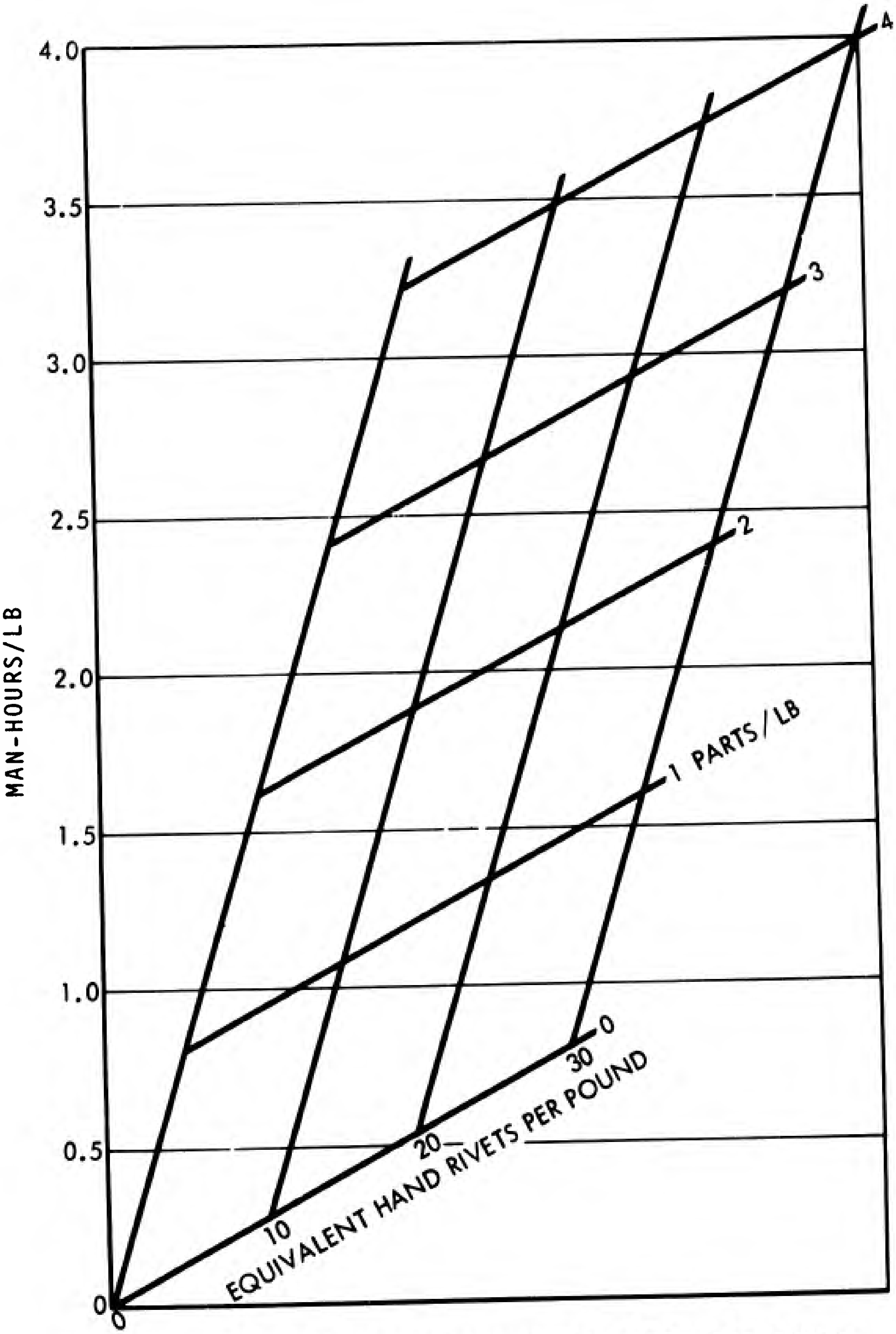

Figure 3. COMBINED CONTRIBUTION OF PARTS PER POUND AND RIVETS PER POUND TO COST

labor hours per pound; a design with four parts and 10 rivets per pound would require about 3.5 manufacturing hours per pound, etc. Armed with this set of relationships, the designer can "trade-off" these factors, taking into account, of course, the usual technical design constraints.

The techniques for an analysis at each level (component or system) are well in hand.* What is not well in hand, in my opinion, are incentives to designers to focus on cost as a key design parameter. We have emphasized schedule and performance over cost for decades now. Turning these priorities around will be difficult indeed.

Even if we can resolve the problem of lack of incentives, however, we face the problem of lack of data with which to conduct the trade-offs. That is, we really have very few good estimating relationships which indicate how costs vary as a function of design change. A great deal of cost research is needed before we can approach this problem with much confidence. Industry representatives may dispute this point, but diligent research of the subject has not revealed the existence of many such CERs.

Another matter for consideration is that of the relevance of past historical data to the "Design to Cost" problem. If industry is to find ways to dramatically reduce costs, the new cost-performance estimating relationships must be dramatically different than those of the past.

Introduce New Technologies

Introduce new technologies to meet the broad, functional design specifications within the cost target.

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* Several reviewers of this paper have questioned whether adequate techniques are at hand to move from one level (component) to the other (system).

Introduce New Manufacturing Techniques

Introduce new manufacturing techniques to further reduce costs beyond the reduction obtained from the design technology.*

D. STANDARDIZE COMPONENTS

Dr. Foster, in his 5 October address [9], stressed the standardization of components. He emphasized two essential elements of standardization: (1) the provision for standard interfaces, and (2) the ability to maintain multiple procurement sources, particularly of critical components and replacement modules. Further, he proposed to develop and test prototype subsystems as separate procurements, aimed for several weapons. When proven, they would then be available for general weapon system use and not be tied to a single proposed weapon system. IDA is undertaking a study of this concept as applied to avionics, and is investigating the possibility of designing standardized modules for fighter avionics.

Standardized components would appear to offer several advantages: first, longer production runs would reduce costs due to the learning-curve effect and would be much further out on the learning curve. A second advantage relates to decreasing maintenance costs. The less-complex designs that should result from standardized components would in themselves have lower maintenance costs and the standardized training of maintenance personnel would further reduce maintenance costs. Third, substantial savings may be possible through reduction of spare parts inventories.

E. INCREASE RELIABILITY AND MAINTAINABILITY

Dr. Fubini was chairman of a recent Defense Science Board panel which investigated the reliability and maintainability of avionics

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* A major thrust of the Defense Science Board Cost Reduction Task Force, chaired by Mr. F. Bucy, will be to recommend ways of using commercial experience in military design objectives, technical requirements, management perspectives, engineering design, data, and field support.

equipment. The panel found that the actual reliability of avionics equipment such as tactical airborne radars, is far below initial specifications for the equipment. This results in high maintenance costs and low operational readiness rates for the weapon systems. Another example concerns navigation systems. IDA analysts have found that the reported reliability obtained in major sophisticated navigation systems is usually only 1/3 to as low as 1/10 of the original specification.

Dr. Fubini has stressed both the need to develop much more realistic specifications for avionics equipment and the need to take steps to ensure that the equipment that is developed will meet those specifications. A second action which he believes to be needed is the development of much better reporting systems for maintainability and reliability to provide feedback to the developers of avionics equipment. This step is essential if we are to improve the capability of contractors to reduce future maintenance costs through better initial designs. A third action, proposed by others, would be to devise incentives for both contractors and military services to improve reliability.* Dr. Foster has suggested the possibility of paying industry for a field-reliability warranty. Such a warranty could be a maintenance contract under which equipment is kept working for an annual fee. Perhaps the reliability warranty would provide the necessary incentive to industry to reduce the field maintenance costs and to do it during the design phase rather than later.

It has been pointed out that such warranties would probably be unacceptable to industry unless they could provide the field maintenance teams. That is, GI maintenance teams have their own "reliability" problems and are not within the control of the contractor. Further, could we risk reliance on such a policy during wartime?

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* That is, and this may be an exaggeration, the contractor has no strong economic incentive to improve reliability. In fact, the reverse may be true in today's market. The procurement agency is concerned with getting a system in the field by the planned operational dates, and the field commander usually gets rated on operational readiness rates, etc., not low maintenance costs. Thus, there seem to be no appropriate incentives to improve reliability.

IV. OBSERVATIONS ON PROBLEM AREAS WHICH MAY LIMIT ACHIEVEMENT OF "DESIGN-TO-COST" GOALS

Four potential problems may limit the success of "Design-to-Cost" goals and should be considered. They are the following:

(1) Uncertainty associated with new technology,

(2) Tendency toward "all success" program estimates,

(3) Institutional bias towards low estimates,

(4) Institutional inertia towards change.

The first problem deals with the uncertainties associated with new technology. In his paper, Dr. Flax discussed the price of entry of new technology by noting, " . . . it is hardly possible to foresee the problems which will arise with new materials, processes, components and techniques in complex combinations which have never been designed and built before." In other words, this is the problem of unknown-unknowns; that is, the UNK-UNK problem, as defined by the Aerospace Industries Association in its 1968 Study [13]. Recall that at that time the aerospace industry was being battered by the public and by Congress for cost overruns and the industry finally had to admit that it did not know how to accurately cost systems involving advanced technology.* Their famous UNK-UNK chart is shown on Figure 4. We note that when the technical uncertainty is reduced, the unknown-unknowns are also reduced. My concern is that the "Design-to-Cost" actions, which I believe are generally meant to be applied to low-technology systems, may be applied to high-technology systems, with the uncertainty element underestimated. For those known high-technology systems, development policies previously discussed should help to reduce cost overruns.

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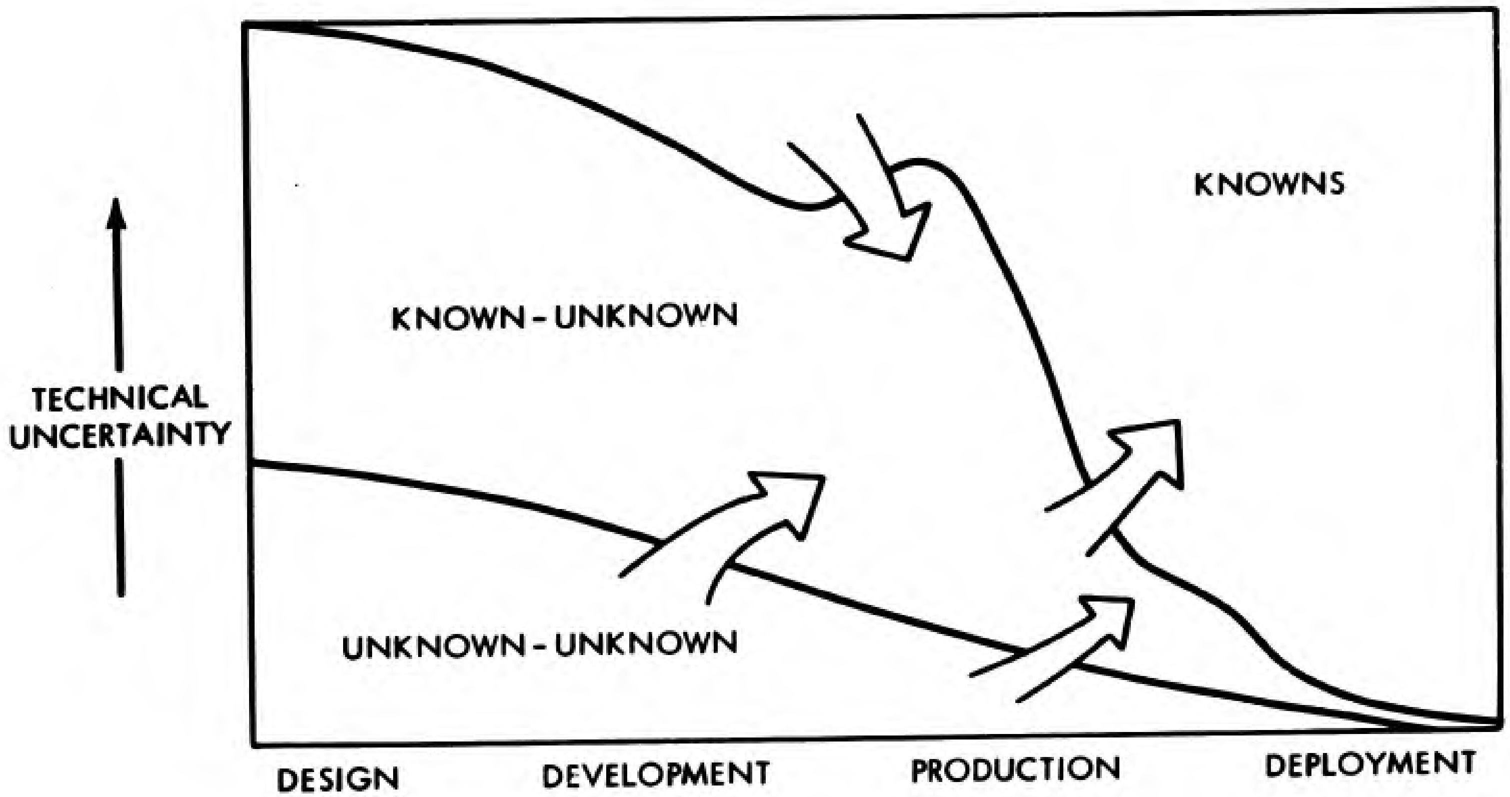
* A frequent industry retort up to that time had been "We must know how to cost equipment or we wouldn't be in business!"



Source: AIA Report, December 1969

Figure 4. UNKNOWNS TO KNOWNS TRANSITION

The second problem deals with the tendency toward "all success" program estimates. It is a fundamental program management problem, not limited to "Design to Cost" programs or to DOD programs for that matter. The question is, should a future system's cost be estimated on the basis of (1) achieving an "all success" program, or (2) the average experience of past similar programs? This problem is the heart of the issue today in DOD between the "independent parametric cost estimate" of the cost analyst and the "industrial engineering estimate" of the project manager. Mr. Packard, in his memo of December 7, 1971, "Use of Parametric Cost Estimates", established a procedure to bring before top management parametric estimates which take into account historical experience. These estimates can then be compared with the industrial engineering estimates of the project manager to aid in judging the validity of the "official" estimates. Most project managers make some allowance for things to go wrong in their estimates, but usually it is a very small allowance. Murphy's Law, that is, "If something can go wrong, it will", seems to apply to all DOD programs.

My concern is that the "Design to a Price" actions are geared to what is essentially an "all success" program, and this poses a dilemma for management. That is, if we are to have low-cost systems, these must be programs essentially free of problems (or be of revolutionary technology!). Yet, history has not been kind to DOD in this regard, or for that matter, to much of the civil area. So, do we make our plans assuming "all success" or do we make a healthy correction for problems likely to arise?

The third problem deals with the institutional bias toward low estimates which exists in all levels of DOD. In March of 1970, Air Force Secretary Robert Seamans summarized the problem as follows:

> In part, cost overruns have been confused with underfunding in the budgetary process. The Air Force has based a budget request on a low target price intended only as the low end of a range of possible costs. Both the target price and the higher ceiling price resulted from negotiations and reflected the

> expectation that final costs would end up somewhere in between. Moreover, extreme competition between contractors led to very low target prices. And within the Services, competition between programs for scarce dollars had a similar effect [14].

All too often the low number got "sold" to OSD because, as Secretary Packard in his departure from OSD noted, one of the factors that " . . . seemed to have gotten us in trouble in the past . . . [was that] cost estimates were unrealistic and accepted even when we could have known better" [4]. (Emphasis mine.) A recent Comptroller General's Report to the Congress [8] stated, "Cost growth in acquiring weapon systems continues to be a significant problem in DOD. Much of this cost growth is attributable to unrealistic cost estimates." (Emphasis mine.) The same pressures that exist among contractors and within the Services also exist at the OSD level because DOD is competing with nondefense agencies for the dollar. My concern here is that this institutional bias will have its effect on "Design to Cost" actions and we will continue to "sell" systems using a low-cost estimate only to discover at the last minute that they are really high-cost systems.

Independent estimates can help by providing management with a second set of estimates of a program. However at a recent DOD Cost Research Symposium in Durham, North Carolina, it was stated that of about ten major systems that had been reviewed by DSARC so far this year, the differences between the "official" System Project Manager's (SPO) estimate and the Service's independent estimate was no greater than 10 percent, and was often as low as 3 percent! The statement was made at a meeting of the panel dealing with the development of "Independent Parametric Cost Estimates" by the Services for review by the Cost Analysis Improvement Group. Members of the Panel were cost analysts responsible for preparing the estimates.

In view of this astonishing degree of correspondence of independent estimates we may optimistically hope that the SPOs' and the contractors' estimates have become more realistic. However, I suspect that institutional bias is still with us, or that the estimators are not independent, or both.

The fourth problem is the very great institutional inertia that exists with regard to change. I am referring here to the task we have of changing the thinking throughout DOD to achieve low cost goals; particularly, to reduce the requirements for high-technology systems. Dr. Fubini [15] has noted that, "Our quest for performance drives costs." As evidence he noted that, in avionics, we miss cost and reliability targets by wide margins, yet meet technical performance goals very well. He believes that we must somehow change our way of doing things if we are to inhibit the continued growth of high-cost systems. DOD Directives will not remedy the situation. There must be fundamental changes in DOD's procurement processes, and we must establish incentives for individual cost consciousness. Dr. Foster put it this way:

> . . . we must change the objectives of the R&D community from the overriding emphasis on improving the state of the art in performance, to an emphasis on quality equipment having an acceptable performance for an affordable cost [9].

My concern then is can, in fact, the Department of Defense and the defense industry itself change?

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