AD-784 335

A QUANTITATIVE EXAMINATION OF COST-QUANTITY RELATIONSHIPS, COMPETITION DURING REPROCUREMENT, AND MILITARY VERSUS COMMERCIAL PRICES FOR THREE TYPES OF VEHICLES. VOLUME II

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Institute for Defense Analyses

Prepared for:

Advanced Research Projects Agency

March 1974

The work reported in this document was conducted under Contract DAHC15 73 C 0200 for the Department of Defense. The publication of this IDA Study does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that agency.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD 784 335
4. TITLE (and Subtitle) A Quantitative Examination of Cost-Quantity Relationships, Competition During Reprocurement, and Military Versus Commercial Prices for Three Types of Vehicles Vol. II		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER S-429
7. AUTHOR(s) Morris Zusman, Norman Asher, Elliot Wetzler, Debbie Bennett, Selmer Gustaves, Gerald Higgins, Carole Kitti		8. CONTRACT OR GRANT NUMBER(s) DAHC15 73 C 0200
9. PERFORMING ORGANIZATION NAME AND ADDRESS INSTITUTE FOR DEFENSE ANALYSES PROGRAM ANALYSIS DIVISION 400 Army-Navy Drive, Arlington, Virginia 22202		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS T-98
11. CONTROLLING OFFICE NAME AND ADDRESS Director of Defense Research and Engineering Engineering and Management Washington, D.C. 20301		12. REPORT DATE March 1974
		13. NUMBER OF PAGES 290
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) cost-quantity progress curve first-unit cost competition procurement		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This volume presents the results of the study which was divided into the following three interrelated subtasks: (1) An analytical and empirical examination of cost-quantity relationships with the objective of laying the framework for other parts of the study and attempting to identify factors other than cumulative units that might be incorporated in the progress curve; (2) An examination of competitive procurements		

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with the objective of examining quantitatively the effect of competition on selling price; and (3) A comparison of prices paid for similar military and commercial equipment with the objective of testing quantitatively the hypothesis that commercial procurement practices are superior to military procurement practices and that, as a result, commercial equipment costs less than similar military equipment. The appendices contain supporting data and analyses.

STUDY S-429

A QUANTITATIVE EXAMINATION OF COST-QUANTITY RELATIONSHIPS, COMPETITION DURING REPROCUREMENT, AND MILITARY VERSUS COMMERCIAL PRICES FOR THREE TYPES OF VEHICLES

Volume II

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Task T-98

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Chapter I

SUMMARY AND FINDINGS

The study was organized into three principal subtasks whose primary objectives were--

(1) To identify and quantify those factors that affect the cost-quantity relationship of a given system.

(2) To quantify the effect of competition on the price paid by the government.

(3) To test the hypothesis that commercial procurement practices result in prices that are less than prices paid by the military for like equipment.

Principal findings of Subtask 1:

- Correlations between the intercept (first-unit cost) and the slope of the progress curve were found for a number of different types of aircraft. The higher the first-unit cost the steeper the slope was likely to be. For a 10-percent increase in first-unit cost, an average reduction of 0.72 percent occurs in the progress-curve slope.
- In aircraft production the lot size[1] was found to be statistically and quantitatively significant. For most aircraft, unit cost could be reduced by increasing the lot size. However, in the few cases where average lot size was very large and statistically significant, the increasing of the lot size increased unit cost.

Principal findings of Subtask 2:

- Significant savings were realized on the first competitive award when competition was introduced during the reprocurement phase of selected programs. For the 20 cases in the data base, the average savings

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[1] For a discussion of the concept of lot size, see Chapter III, Section G.3.

were 37 percent. The amount of the savings was directly correlated with the sole-source progress-curve slope and the type of competition. The flatter the sole-source progress curve the greater the saving observed was likely to be. With respect to type of competition, a winner-take-all competition resulted on average in a greater percentage of savings being observed than a competition in which the competitiors were competing for a share of the total award rather than the whole award. However, the effect of a winner-take-all competition on the course of future competitions could not be determined from the available data.

- The post-competitive progress curve is characterized by a lower intercept (first-unit cost) and a flatter slope than the sole-source progress curve. This means that the gross savings (from what would be expected to be paid if the sole-source progress curve were extrapolated), measured in percentage terms, will decline for each succeeding competitive award.

Principal findings of Subtask 3:

- No significant price difference could be found between similar commercial and military noncombatant aircraft or wheeled vehicles when prices were compared on a basis of vehicle empty weight. Nor were significant price differences found between similar commercial and military noncombatant ships when prices were compared on a basis of useful load-carrying capacity. Military transport aircraft were found to cost significantly less than commercial aircraft when they were compared on a basis of useful load-carrying capacity. The reader is cautioned that, since this finding is based on only three different types of vehicles, it should not be generalized to other types of products; nor should it be used to infer that military procurements cannot be made more efficient.

Chapter II

INTRODUCTION

The genesis of this study is the Department of Defense's growing concern with the rapidly rising procurement costs of military equipment. This concern is intensified by the fact that the percentage of the DoD budget available for research, development, test, and engineering and procurement has been falling--due to higher manpower costs. In 1964, 45 percent of the DoD budget was allocated for RDT&E and procurement, while in 1973 it will be only 30 percent. Further, over this same period of time, the DoD budget has decreased as a percentage of the gross national product. If the Department of Defense is going to be able to procure in sufficient quantities the types of equipment it needs, it will have to find means to reduce costs of these weapons systems. Among its efforts to reduce costs, DoD had a task force on "Design-to-Cost," in which a number of experts made recommendations on how DoD procurement practices might be modified to achieve greater efficiency.

The Institute for Defense Analyses (IDA) was asked under Contract No. DAHC 15-73C 0200 to examine quantitatively some aspects of the effect of competition and of the effect of quantity-production parameters on the cost of DoD equipment. Because cost-quantity relationships are involved in all the weapons systems procured by the Department of Defense, the IDA analysis was performed within the framework of cost-quantity relationships, more commonly referred to as learning curves or progress curves.

This study is divided into the following three separate but interrelated subtasks:

- *Analytical and empirical examination of cost-quantity relationships.* Because it has been found that the basic progress curves are applicable to almost all production parameters no matter how diverse,[1] the progress curves have been chosen as the structure of this study that examines prices paid by the government for a diverse variety of goods. The objective of this subtask has been to lay the framework for the other parts of the study and to attempt to identify factors other than cumulative units that might be incorporated in the progress curve. Ideally, these other factors are ones that can be controlled to reduce cost.
- *Examination of competitive procurements.* The objective of this subtask was to examine quantitatively the effect of competition on selling price.
- *Comparison of prices paid for similar military and commercial equipment.* A commonly held belief is that commercial procurement practices are superior to military procurement practices and that, as a result, commercial equipment costs less than similar military equipment. The objective of this subtask is to test this hypothesis quantitatively for the limited class of equipment for which roughly comparable military and civilian counterparts could be established and for which data were readily available.

Because the study was primarily quantitative in nature, it has been heavily dependent on the availability of data. Unfortunately, as is explained in the report, there is a dearth of data of the type required to address the questions of this report in as much detail as might be desired. Therefore, the areas of examination and the scope of the findings are much more restricted than originally intended. For example, the data needed to examine cost-quantity relationships empirically and in detail were available only for the manufacture of aircraft; and, therefore, our analysis of the basic cost-quantity relationship was limited to aircraft. Further, it had been intended to examine quantitatively the effect of competition starting with the initial design and carrying forward through

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[1] *Perspective on Experience* [1] presents data on how progress curves fit price data for a large variety of products, ranging from integrated circuits to beer.

production; but because the data do not exist for so broad an analysis, the inquiry had to be limited to examining the effect of competition in the reprocurement phase, where there was a limited amount of quantifiable data. Likewise, in making comparisons between military and commercial prices, we are not able with the limited data to address the question of whether the military is specifying its equipment to meet higher performance requirements than are realistically required. On the other hand, we have tried to address the widely held belief that factors in addition to performance requirements cause higher prices for DoD equipment.

This report consists of an Executive Summary (Vol. I), chapters below dealing with each of the three subtasks outlined above, and 10 appendices of supporting data and analyses.

Chapter III

ANALYTICAL AND EMPIRICAL EXAMINATION OF SELECTED VARIABLES THAT AFFECT THE COST-QUANTITY RELATIONSHIP

The objective of this subtask was to analyze the basic cost-quantity relationship, as well as to identify and quantify, where possible, additional variables that affect cost. Particular attention was given to additional variables that could be controlled, such as lot size and production rate.

A. BASIC MODEL

The basic cost-quantity relationship is variously referred to as a progress, learning, or improvement curve. The progress curve relates the average or unit cost of a product to the cumulative quantity produced. On log-log paper, the standard progress curve is a straight line. While some writers make certain distinctions (learning curves might apply only to man-hour cost variations with quantity; progress curves might apply to total cost variations with quantity), others use the terms interchangeably. We use the terms interchangeably and in the widest sense. The basic form of the progress curve in common usage is

$$MC = F \times N^{L} \qquad (1a)$$

$$TC = \frac{F}{L + 1} \times N^{L+1} \qquad (1b)$$

$$CA = \frac{F}{L + 1} \times N^{L} \ , \qquad (1c)$$

where

MC = the marginal cost of producing the Nth unit;
TC = the total cost of producing N units;
CA = the cumulative average cost of producing the N units;

F = the "hypothetical" cost of producing the first unit;[1]
N = the cumulative number of units produced; and
L = the progress-curve exponent.

Since the progress curves are empirically derived from the available cost-quantity data, implicitly embedded in them are the contributions to cost reduction achieved through experience by all activities related to the manufacture of a product (e.g., management, manufacturing, engineering, procurement, etc.).

Reference to the steepness of a progress curve is generally made in terms of a percent slope. For example, an 80-percent progress curve has an exponent L of -0.322, which means that every time the quantity is doubled, the unit cost is reduced by 20 percent. Figure 1 illustrates two progress curves, one with an 80-percent slope and the other with a 75-percent slope. As can be seen by Figure 1, the smaller the percent slope the steeper the curve. The exponent and slope are related to each other by

$$L = \log\ (\text{slope in percent}/100)\ /\ \log 2\ .$$

If N were a continuous variable, then the three equations (1a-1c) would be completely compatible with one another. The marginal or unit cost equation (1a) is the derivative of total cost TC with respect to cumulative number produced N. Equation (1c) is simply total cost TC divided by cumulative number produced N. Since N is discrete and not continuous, these equations are all reasonable approximations for each other for $N > 10$.

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[1] Note that the "first-unit" cost referred to throughout this report does not represent the measured cost of the first unit, but is the solution of a regression equation (fitted though all the cost-quantity data available) at the point where the cumulative quantity is 1.0. When only lot (as opposed to unit) cost-quantity data were available, a progress curve was derived by using an iterative regression technique developed by the Defense Contract Audit Agency (and described in [3]).

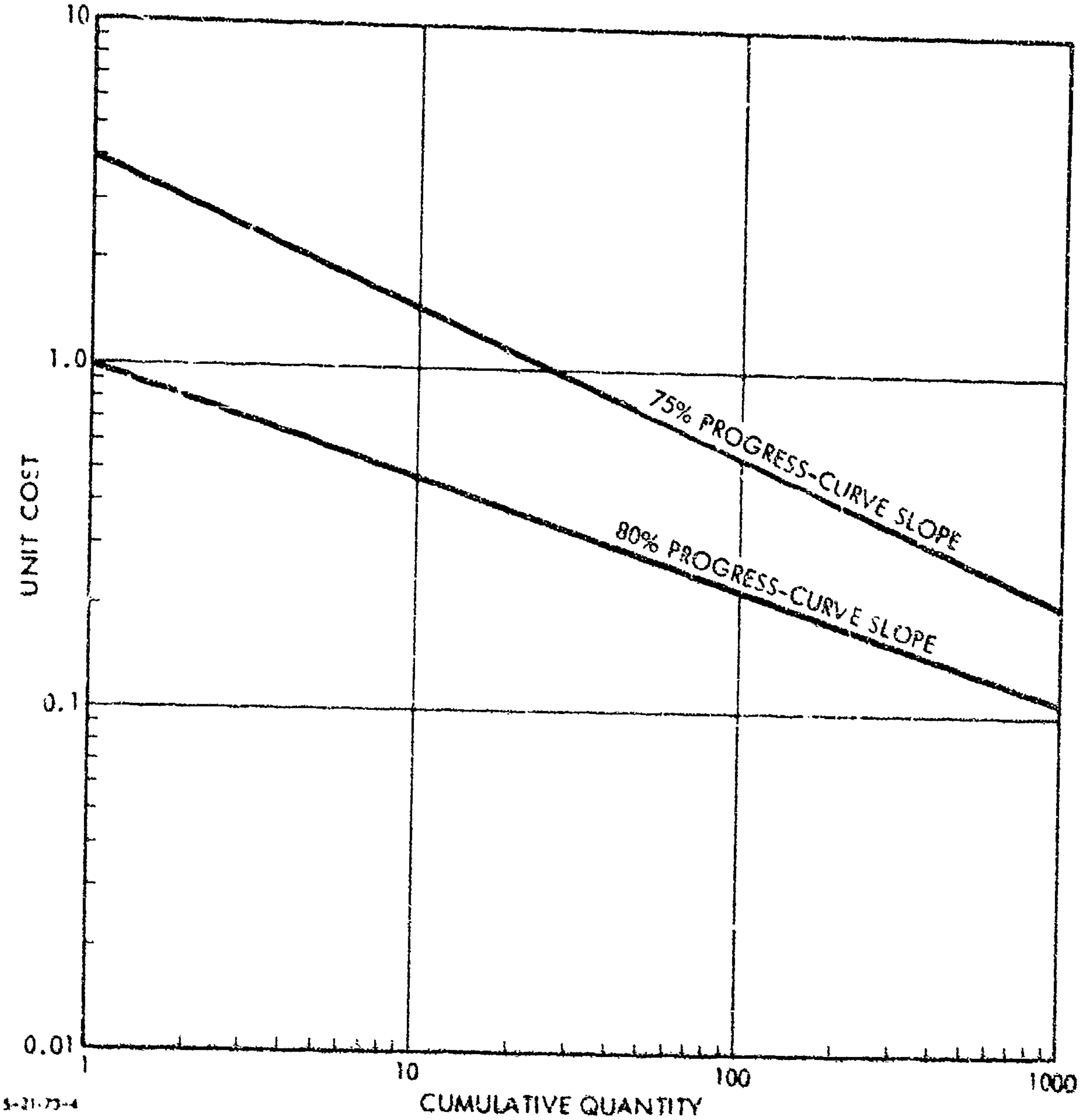

Figure 1. TYPICAL PROGRESS CURVES

While non-log-linear progress curves have been formulated,[1] the log-linear form, as given by Equations (1a) through (1c), has the following to recommend it:[2]

- *It is consistent with most of the historical variation in cost of production.* For example, the average of the coefficients of determination (R^2) for 78 aircraft and helicopters using Equation (1c) was 0.915.[3] That is, variations in cumulative output using a simple progress-curve equation explained 91.5 percent of the variation in average cost. (See Appendix C for details.)
- *The computation involved is simple.* As already illustrated, the relationship plots as a straight line on log-log paper.
- *The log-linear curve is almost universally used in planning work.*

The almost universal acceptance of the basic progress-curve model may be one reason that the model has such high explanatory power. More specifically, Harold Asher [5] cites those who believe that the linear progress curve is the result of the method generally used by airframe producers in production scheduling and man-hour budgeting, a method that assumes the linear hypothesis.

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[1] At small amounts of cumulative output, it has been suggested that a progress curve that is convex from below is a more accurate representation of the relationship between unit cost and cumulative output [4]. At large amounts of cumulative output, it has been suggested that a progress curve that is concave from below (flattening) is a more accurate representation [4, pp. 98-102]. If both of these suggestions are adopted, then a backward S-shaped progress curve is obtained.

[2] In the case of progress curves, a statistical analysis of alternative forms usually does not indicate that one form is superior to others. See, for example, Armen Alchian [6].

[3] It is necessary to note that some of these regressions may exhibit a significant positive autocorrelation of the residuals, as reflected by a low Durbin-Watson statistic. Significant autocorrelation gives an upward bias to the coefficient of determination (R^2). To prevent high autocorrelation requires the use of "generalized" least squares in place of "ordinary" least squares; however, generalized least squares cannot be used without *a priori* information on the structure of the autocorrelation.

Since we have presented the progress curve in some detail, it is a good starting point for asking two basic questions:

(1) What are the conditions that influence the first-unit cost and slope of the progress curve?

(2) What are some of the variables, other than cumulative output, that have a significant impact on unit cost?

For each of these two questions, we have examined in this subtask three important relationships. For the first question, we have analyzed--

- The effect of different levels of product performance on the intercept of the progress curve.
- The relationship between the intercept and the slope of the progress curve.
- The effect of large cumulative output on the slope of the progress curve (i.e., whether or not the progress curve flattens out).

On the second question, we have studied--

- The effect of production rate on unit cost
- The effect of lot size on unit cost
- The effect of model changes on unit cost.

In addition to the examination of the progress-curve literature, data were analyzed from the Cost Information Reports (*Aircraft Learning Curves*) of the Naval Air Systems Command [7].[1]

B. THEORETICAL INTEGRATION OF PROGRESS AND COST CURVES

Before going directly to a discussion of the six listed topics, we present a brief statement of theoretical attempts to combine progress curves and cost curves.

The initial development of the concept of a progress curve (first applied to airframes by Wright [9]) was based primarily on empirical observation rather than on some *a priori* theoretical

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[1] Budget data were also analyzed for airframe and electronics, but did not shed much light on the six topics listed above.

structure. Since then, a firmer theoretical basis has been developed. Some theoretical work has been done by economists to integrate cost curves (which relate unit costs to rate of production) and progress curves (which relate unit costs to total output). Theoretical integrations of these two kinds of curves have been done by several well-known economists. Articles by Alchian [9], Hirschleifer [10], and Oi [11] extend the basic cost curves used by economists to incorporate total volume of output, time period of production, rate of production, and planned delivery date. These articles contain various propositions about the relationships between these variables. These theoretical propositions, based on the economic concepts of factor substitution and joint production, are compatible with an inverse retlationship between unit cost and cumulative output.

Although these integrations of cost and progress curves are independent of on-the-job learning or technical change, another important article (by Arrow [12]) accepts the idea that learning by labor during the production process leads, as output accumulates, to some fall in unit costs. But, believing that there are diminishing returns to this kind of learning, Arrow hypothesizes the continual introduction of new types of capital, which act as a stimulus to learning by labor. The hypothesis of a new stimulus is important in generating the constant rate of learning shown by the log-linear form of progress curve. However, Arrow does not identify the source of the new machinery that changes the workers' environment; he may be assuming implicitly some kind of tehnical progress affecting the inputs but not the production process itself.

In spite of the different economic explanations of progress curves discussed above, the interpretations are not mutually exclusive. Empirically derived progress curves are likely to combine various economic factors, and the impacts may be hard to separate.

C. OTHER EMPIRICAL WORK

Despite the theoretical work indicating that a small number of additional explanatory variables should be incorporated in the basic cost-quantity relationship (a primary variable being rate of production), only a few empirical studies in the 37 years since the original Wright article [8] have tried to incorporate other variables into the progress curve. These studies sometimes have either statistically inconclusive or seemingly conflicting results as far as the effects of these other variables. (Some of these studies are discussed in Appendix D, below.) There appear to be three major reasons for the sometimes inconclusive and seemingly contradictory results of these studies:

- *Lack of empirical data.* Accurate quantitative data are not ordinarily collected or kept for variables (such as rate of production) that theory indicates should be incorporated in the progress-curve equation.
- *Difficulty of observing effects.* The high explanatory power of the basic model and the correlation that other explanatory variables (e.g., rate of production) have with cumulative output make it difficult to observe statistically the effects of these other variables.
- *Use of inaccurate mathematical form.* These other variables are entered into the right-hand side of the progress-curve equation in the same way that cumulative output is entered (i.e., usually in a log-linear form). From a theoretical standpoint, as will be explained below (Section G of this chapter), additional explanatory variables (such as production rate or lot size) entering in the same way as cumulative output misspecifies the way these variables should enter.

D. PROGRESS-CURVE SLOPE VERSUS CUMULATIVE NUMBER PRODUCED

We will now proceed to examine the three topics presented under the first of the two basic questions asked in Section A, above:

(1) The effect of different levels of product performance on the intercept of the progress curve.

(2) The relationship between the intercept and the slope of the progress curve.

(3) The effect of large cumulative output on the slope of the progress curve (i.e., whether or not the progress curve flattens out).

Examination of Figure 1 (above) shows that unit cost continuously decreases as cumulative output increases. However, at some level of cumulative output, it is reasonable to expect that no further reduction in cost can be obtained by increasing cumulative output. But there is a question of whether the slope is likely to change over the range of cumulative output experienced by expensive types of military systems such as aircraft, missiles, tanks, ships, etc. This flattening of the progress curve should be distinguished from the "toe up"[1] phenomenon that is frequently observed when a program comes to the end of its production run. While "toe ups" are undesirable, because of their transient nature, they have significantly less impact than flattening does on total program cost.

Most of the aircraft data observed do not show signs of any significant flattening of the progress curve, but the aircraft do not have production runs much in excess of a thousand. The few aircraft that do show signs of having their progress curves flatten out significantly are often involved in model changes.

We examined the pattern of "residuals"[2] in our regression equations for five aircraft (fighter and attack types) whose cumulative output was greater than a thousand. A pattern of

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[1] The "toe up" phenomenon is one in which the last few units produced cost more than the previous units produced, in contrast to what the progress curve would predict. Numerous reasons have been given for the "toe up," including the shifting of experienced workers to other programs, the running out of parts, etc.

[2] "Residuals" are deviations from the fitted line.

residuals shown by Figure 2 would strongly imply a flattening of the progress curve. Two of the five aircraft, the AD and the A-4, had this pattern of residuals. If the observations fall within the data envelope shown by Figure 2, then the residuals have a positive-run, negative-run, positive-run pattern. Given this pattern, we can expect the flattening point to occur approximately at the middle of the negative run of residuals. We discuss the curvature of the progress curve in terms of a flattening point (as illustrated by Figure 2) for expositional and statistical convenience. A more accurate representation of flattening probably would be given by a gradual curvature of the progress curve. The regression line, taking the flattening effect into account, would be the dashed line in Figure 2. Statistical problems occur in the actual estimation of the dashed line in Figure 2, if we use "dummy" variables. To obtain the dashed line to the right of the flattening point, it is logically necessary to have a "slope" dummy and an "intercept" dummy associated with cumulative output. However, the slope and intercept dummies have an extremely high intercorrelation ($r > 0.99$), which makes the estimated coefficient values for the slope and intercept dummies unreliable. If only a slope dummy is used, then a biased estimate occurs in both the estimate of the slope-dummy coefficient and in the estimate of the flattening point (i.e., the amount of flattening is considerably underestimated and the cumulative quantity at which it occurs is considerably overestimated). Therefore, in view of these problems, we estimated the dashed line by completely segregating the data into two nonoverlapping groups and running a regression equation of the form

$$\ell n C = a_1 D_1 + a_2 D_2 + a_3 D_1 \ell n N + a_4 D_2 \ell n N \ , \qquad (2)$$

where

$D_1 = 1$, if $N < K$; and $D_1 = 0$, otherwise; and
$D_2 = 1$, if $N \geq K$; and $D_2 = 0$, otherwise.

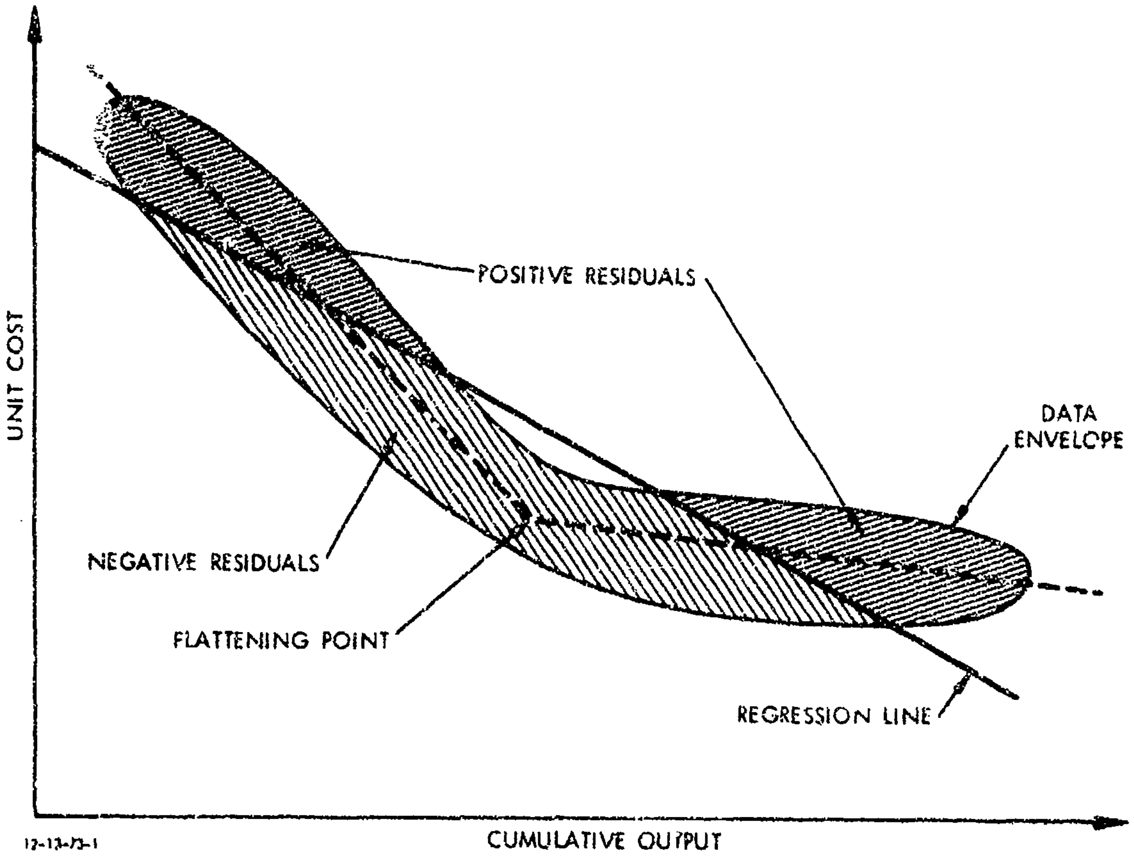

Figure 2. PATTERN OF RESIDUALS

The flattening point K was chosen by trying several values and selecting the one that maximized R^2 (coefficient of determination).

The regression results statistically supported the proposition that flattening of the progress curve occurred for the AD and A-4 aircraft. Even in the case of these two aircraft, the results were not completely unambiguous, because of the effect of an introduction of a model change. The apparent flattening point was around 460 aircraft for the AD and 790 aircraft for the A-4. The specific statistical results are given in Appendix A.

A cross-sectional analysis of the effect of cumulative quantity on flattening of the progress curve was made for six aircraft types. The regression equation used had the form

$$\ell n G = a + b \ell n F + c \ell n N^* , \tag{3}$$

where

G = percent slope of the progress curve;
F = first-unit cost in man-hours per pound; and
N* = total quantity produced.

The reasons for inclusion of first-unit cost F in Equation (3) are given in Section F of this chapter. Of the six aircraft types, two showed statistically significant and positive coefficients and four showed not-statistically-significant coefficients on cumulative output. These statistically significant and positive coefficients occurred for bomber and fighter aircraft, which indicated progress-curve flattening for these aircraft types. The small numerical value of the coefficient associated with N* suggests a gradual flattening of the progress curve. The regression results for the two types of aircraft that had statistically significant coefficients were (for bombers)[1]

$$\ell n G_b = 3.956 + 0.069 \ell n N_b \qquad (R^2 = .91;\ DF = 4) \tag{4a}$$

and (for fighters)

$$\ell n G_f = -4.461 - 0.076 \ell n F_f + 0.019 \ell n N_f \qquad (R^2 = .59;\ DF = 15) , \tag{4b}$$

where all coefficients are statistically significant at the .05 level; R^2 = coefficient of determination; and DF = degrees of freedom.

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[1] For bombers, first-unit cost F did not have a statistically significant coefficient at the .05 level. An equation was run for bombers with cumulative output as the only explanatory variable; the results of that run are given by Equation (4a).

Analysis of the limited data indicates that the point at which the progress curve flattens out (if such a point exists) varies considerably for different products--and even within a product class. Conway and Schultz [13] present two examples, both with steep progress-curve slopes, based on direct man-hours per unit as the cost measure, that can be used to illustrate the wide variance in the point where the progress curves flatten out. The first example is the production of small parts where the labor content of each unit is measured in hundredths of an hour. The progress curve follows a 74.7-percent slope until 8 million units are produced, at which point the curve flattens out. The second example is the final assembly of an electronic unit where the assembly costs were measured in terms of hours. Here the progress curve follows a 72.9-percent slope until 20,000 units are produced, at which point the progress curve flattens out.

It should be noted that the absolute reduction in cost that occurs as cumulative quantity increases becomes progressively smaller for a typical progress curve, as shown by Figure 3. Thus, only a small difference in absolute cost appears if the flattening point is at A (in Figure 3) and the cumulative quantity produced is at B.

E. EFFECT OF PERFORMANCE ON COST

It is obvious from Figure 1 that unit cost depends on both the slope and the intercept (i.e., first-unit cost) of the progress curve. What determines first-unit cost therefore becomes an important subject of analysis. A number of studies have examined this subject and, in almost all cases, have

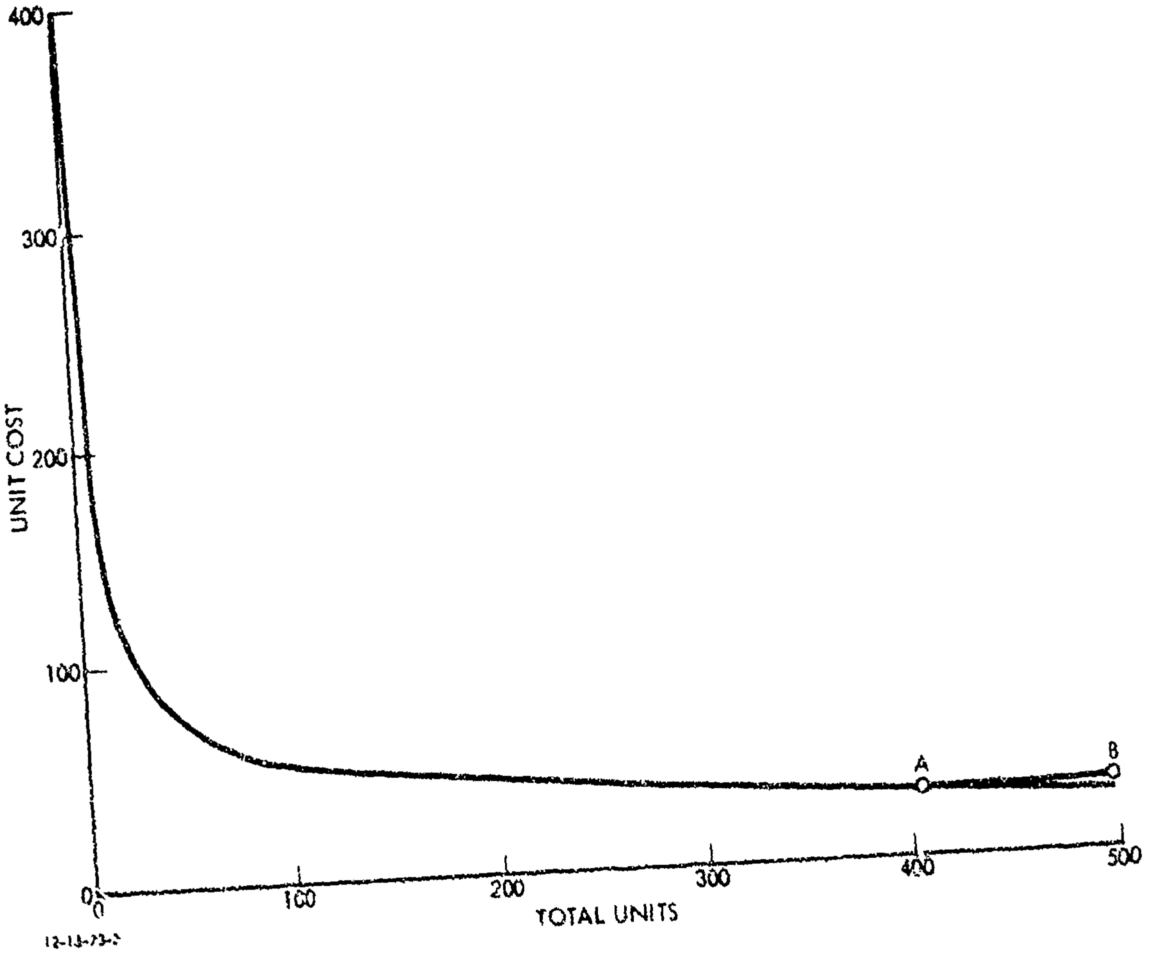

Figure 3. SEVENTY-FIVE PERCENT PROGRESS CURVE DRAWN ON ARITHMETIC GRID

concluded that cost is strongly related to performance requirements.[1]

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[1] These studies usually do not explicitly examine first-unit cost and performance; they examine unit cost and performance for some specified cumulative quantity. However, the implication of these studies is that cost-performance trade-offs exist for any specified level of cumulative quantity. Four representative examples of such studies are (1) *Cost Estimating Relationships for Safeguard Air Vehicles* [14]; (2) *Fire Control Radar and Airborne Computer Cost Prediction Based on Technical Parameters* [15]; (3) *Cost Evaluation and Cost Estimating for Shipboard Electronic Equipment* [16]; and (4) *Cost-Estimating Relationships for Aircraft Airframes* [17].

Inertial navigation systems are presented here to illustrate the relationship between first-unit cost and performance. These systems were selected for several reasons:

- An inertial navigator is a fairly expensive piece of avionic equipment.
- Performance parameters are essentially one-dimensional (the radial error rate).
- IDA has done considerable work in the area of navigation equipment cost and has an extensive data base on this equipment.[1]

Because the black boxes making up an inertial navigation system interface with many other pieces of equipment and may or may not include computers, digital convertors, and displays, it was necessary to separate the cost of the inertial sensors from the costs associated with the computers, digital convertors, and displays. This separation was made subjectively, following the rule that only the cost of equipment (sensors, power supplies, and electronic controls and displays) necessary to run the inertial navigation set are part of the sensor cost. Figure 4 presents a plot of inertial sensor first-unit cost (in 1970 dollars) versus radial error rate.[2] The regression shown in Figure 4 had a coefficient of determination of 0.942. That is, the one performance parameter (radial error rate) explained 94 percent of the variance in the first-unit cost variable. The steep slope of the cost-estimating relationship illustrates how strongly performance affects cost. An inflexible requirement for an inertial navigator with a radial error rate of 0.5 knots (when a radial error rate of 1.5 knots would satisfy

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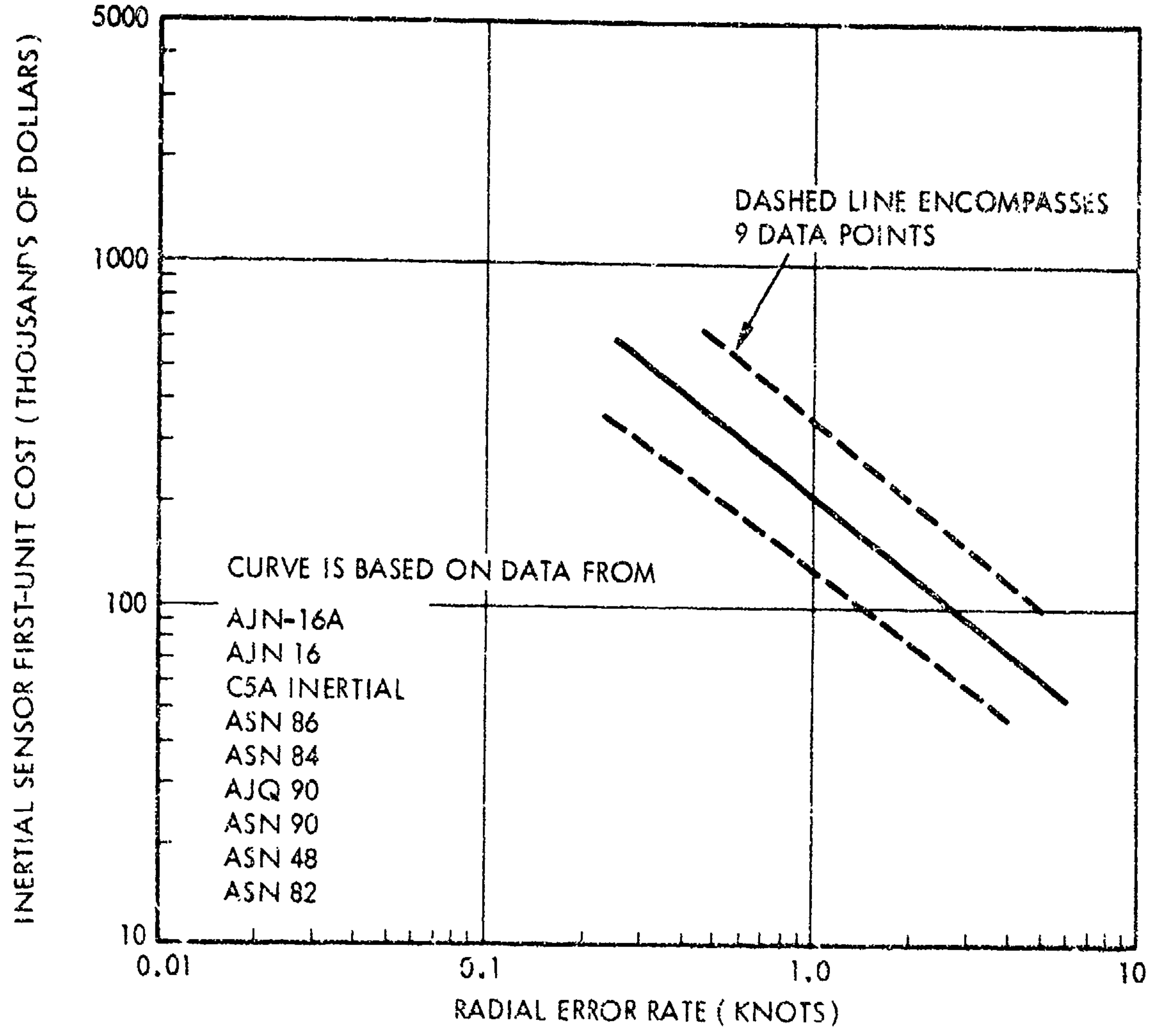
[1] The performance cost relationships presented here were originally developed in *Cost and Performance of Airborne Navigation Systems* [18].

[2] To prevent this report from being considered classified, data points were deleted from Figure 1. Curves with the actual data points are available to all authorized government personnel with a need to know.



*REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION (R^2) = 0.942.

SOURCE: "Cost and Performance of Airborne Navigation Systems," Institute for Defense Analyses, R-181, December 1971.

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Figure 4. INERTIAL NAVIGATION SENSOR FIRST-UNIT COST VERSUS RADIAL ERROR RATE

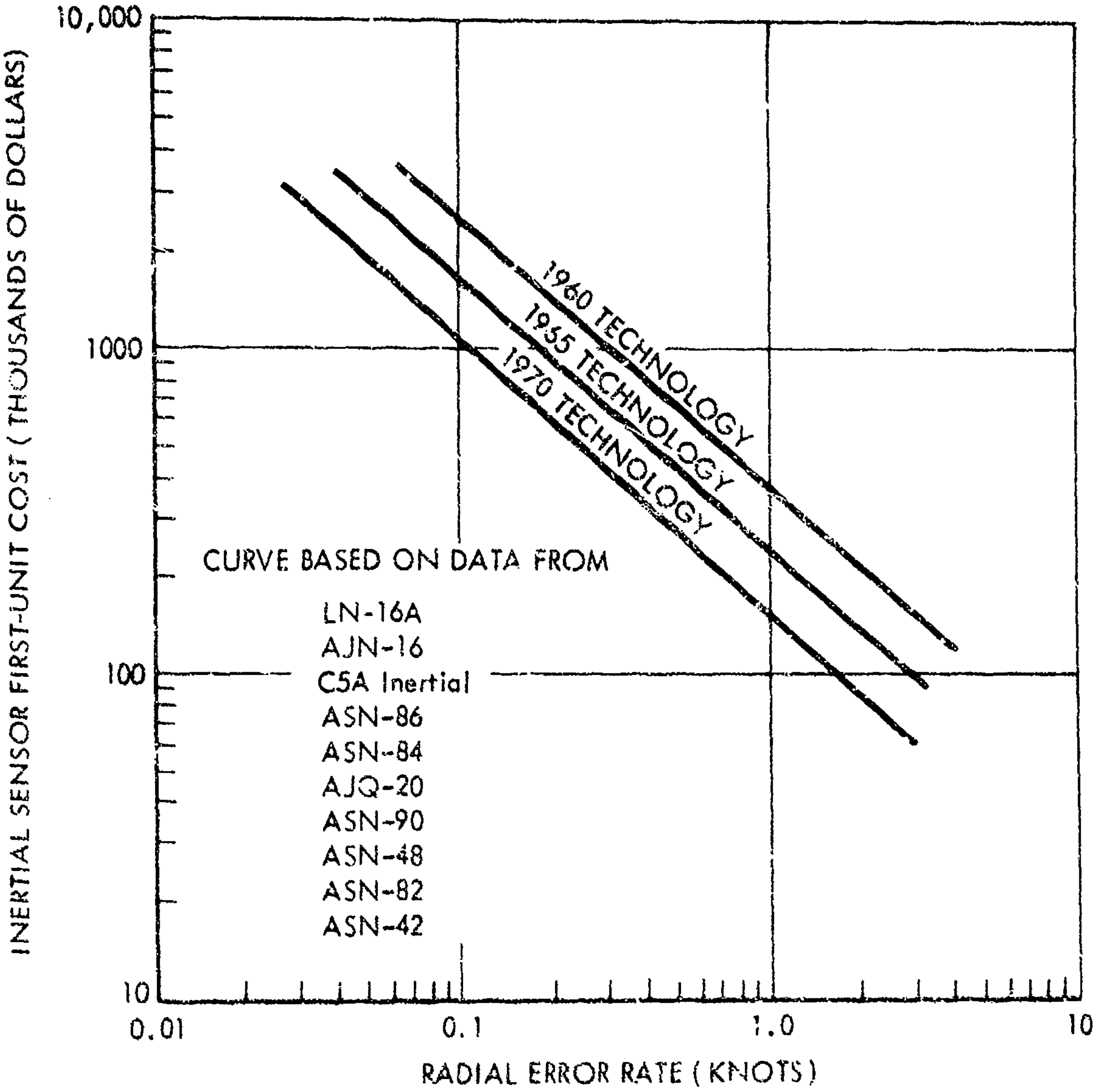
mission requirements) unnecessarily increases first-unit production costs by 129 percent.

Another useful insight can be gained by analyzing the first-unit cost of inertial navigation systems over time. Inertial navigation systems are a particularly good illustration because, unlike many other systems, both low- and high-performance systems have recently been built. Over time, especially in rapidly developing fields such as inertial navigation, advances in the level of available technology should have a noticeable effect on first-unit cost. To test this hypothesis, a second regression was run to derive an estimate that included calendar time as an additional variable. Figure 5 illustrates that for constant performance the cost of an inertial system is decreasing at the rate of 9 percent per year. The coefficient of calendar time is statistically significant at the .05 level.

It would appear from this discussion and from past work of IDA and others, that high-performance requirements are a primary cause of high production costs. While this study could have been devoted to deriving cost-performance relationships for a variety of other equipment, we believe that, having indicated that performance requirements are a major cause of high cost, the rest of the study assumes that performance requirements are given. Additional results relating cost to performance are not needed to identify and quantify other factors that affect cost.

F. FIRST-UNIT COST VERSUS SLOPE RELATIONSHIPS

It is not possible simply to look at a product's progress curve and determine whether the curve is efficient. A progress curve with a high first-unit cost (bad) might have a steep slope (good), and vice versa. It is generally accepted that higher-performance products have higher first-unit costs, an illustration of which was given by the inertial sensor system. Since higher performance normally implies a more sophisticated and complex product for a given state of technology, it is logical to assume that more learning (i.e., a steeper slope) can be achieved when a product has a high first-unit cost.



*REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION $(R^2) = 0.902$.

SOURCE: "Cost and Performance of Airborne Navigation Systems," Institute for Defense Analyses, R-181, December 1971.

5-18-73-6

Figure 5. INERTIAL NAVIGATION SENSOR FIRST-UNIT COST AS A FUNCTION OF RADIAL ERROR RATE AND CALENDAR TIME

Since high first-unit cost is associated with high-performance products, it follows that there is a negative relationship between first-unit cost and slope. The first-unit cost and

and slope data[1] for various aircraft types support this relationship, as illustrated by the plots for fighter aircraft in Figure 6. In this figure, the progress-curve slope is measured for 22 fighter aircraft on the vertical axis, and the corresponding first-unit cost is measured on the horizontal axis. A negative relationship between first-unit cost and slope is found for all aircraft types, as illustrated by Table 1.

Table 1. SLOPE VERSUS FIRST-UNIT COST FOR DIFFERENT TYPES OF AIRCRAFT

Aircraft Type	Percent Reduction in Slope for 10-Percent Increase in First-Unit Cost	Coefficient of Determination (i.e., R^2)	Number of Aircraft Models (by type)
Attack	0.40	.14	9
Bomber	0.60	.37	8
Cargo	0.33	.42	12
Fighter	0.74	.52	22
Helicopter	0.82	.52	16
Trainer	1.42	.92	11

The line shown in Figure 6 provides a weak measure of the efficiency of a particular program. Points falling below this line indicate equipment produced more efficiently than the industry average; points above this line indicate equipment produced less efficiently than the industry average. Of course, since for any particular program the relative importance of the first-unit cost and slope is dependent on the number of units to be produced (i.e., if only a small number are produced, low first-unit cost is more important than slope), the line is not a universal measure of efficiency.

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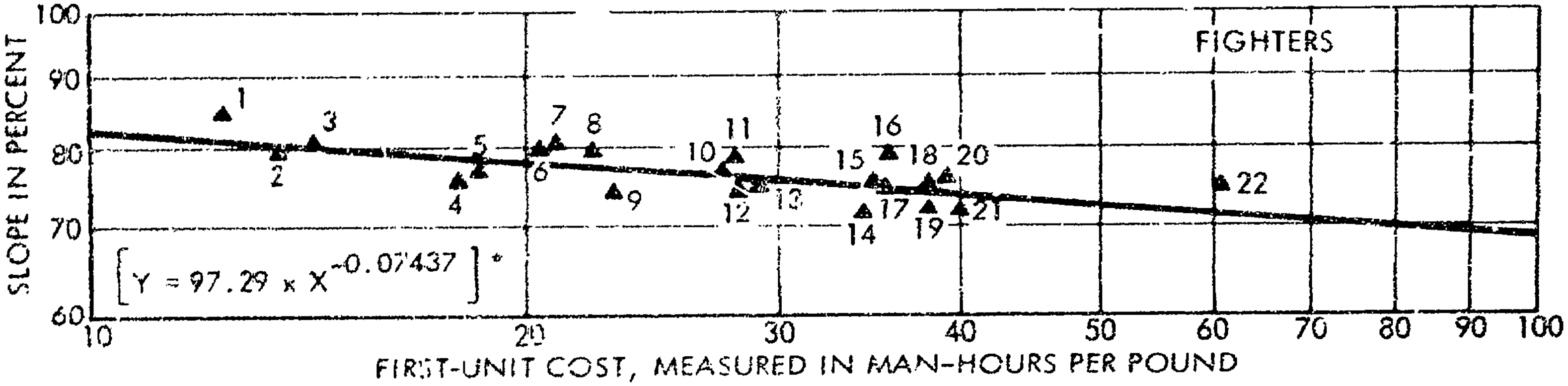
[1] The best available cost data were in terms of direct manufacturing man-hours per pound Therefore, all the progress curves pertaining to aircraft were derived in terms of direct man-hours per pound rather than dollars.



$\left[Y = 97.29 \times X^{-0.07437} \right]^{*}$

LEGEND:

1 = F-89A,B,C,D,H
2 = F-4U-5N
3 = F-86F
4 = F-100C,D
5 = F-94C
6 = F-101B
7 = F-105D
8 = F-104A,C
9 = F-1E/AF-1E
10 = F2H-1,2,2N,2P
11 = F-8A,C,D
12 = F-80A,B,C
13 = F-10A,B
14 = FJ-2
15 = F-3B/MF-3B,F-3C,F-3H-1
16 = F-4 SERIES
17 = FH-1
18 = XF7U-1/F7U-1,3,3M,3P
19 = F-106A
20 = F-102A
21 = RF-84F
22 = F-6A

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION (R^2) = 0.52; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

3-18-71-9

Figure 6. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: FIGHTERS

The negative relationship between slope and first-unit cost also has implications for the high-performance/low-performance force mix. For example, a higher-performance fighter whose first-unit cost is twice that of a lower-performance fighter might be expected to have a unit cost only 1.4 times as expensive as the lower-performance fighter at the hundredth unit.

G. THE IMPORTANCE OF ADDITIONAL EXPLANATORY VARIABLES

Having examined in Sections D, E, and F) the first of the two basic questions asked in Section A, we will now explore the second basic question and the three topics under it--namely, the effect on cost of (1) model change, (2) production rate, and (3) lot size.

The relationship between cost and each of these variables is given in the three subsections of this section. Of these variables, lot size appears to be of particular importance, from two standpoints: (1) it frequently shows up as having a significant effect on cost, and (2) it is a factor that can be controlled. Table 2 shows the improvement in the R^2 (adjusted for degrees of freedom) that occurs by adding additional variables to the regression equations. For each aircraft type, either lot size or production rate was one of the additional variables added to the regression equation. Because of data limitations, it was not possible to include both lot size and production rate in the same regression equation. Whether or not model-change variables were added depended on the particular aircraft model. The regression-equation results for each aircraft are given in Appendix A. The regression equation used was of the form

$$\ln m = a_1 + b_1 \ln N + \sum_{i=2}^{k} b_i \ln Z_i \; . \qquad (5)$$

Table 2. IMPROVEMENT IN R^2 BY ADDING ADDITIONAL INDEPENDENT VARIABLES[a]

Aircraft Model	R^2 (Cumulative Output Alone)	R^2 (Cumulative Output and Other Independent Variables)	Other Independent Variables[b]	Number of Observations
Attack Aircraft				
AD	.721	.942	S, F, D4	57
A-4	.843	.981	S, F, D1	43
A-3	.930	.941	S, D1	16
Bombers				
B-52, Seattle	.884	--[c]	--[c]	53
B-52H, Wichita	.967	.972	X	19
B-58	.978	.979	X	54
B-52G, Wichita	.990	.993	X	29
Cargo Aircraft				
C-130	.846	.978	S, D1	26
C-123	.872	.932	S	22
C-124	.876	.895	S, D1	22
KC-135	.952	.964	X	72
C-119	.952	.953	S	45
C-82A	.964	--[c]	--[c]	14
Fighters				
F-100	.657	.969	S, D3	35
F-89	.670	.898	D1	34
F-94	.829	.855	S	13
F-86	.851	.935	S	44
F-J2	.919	.987	S, D1	16
F-84	.921	.961	S	22
[illegible]	.953	.976	S, D2	22
F-80	.977	.984	S, D1	23
F-8	.977	.983	S	34
F-101	.986	.988	S	14
F-3	.985	--[c]	--[c]	19
Miscellaneous Aircraft				
O-1A,B	.072	.912	S, D1	32
P-3	.977	.986	S	21
Trainers				
T-33	.726	.786	S	63
T-28	.964	.978	S	20
T-37A,B	.991	--[c]	--[c]	19

[a] Dependent variable is man-hours per pound of airframe.

[b] S = lot size; F = flattening of slope (i.e., slope dummy on cumulative output), X = production rate, and Di = model-change variables (i = the number of such variables).

[c] No improvement in the R^2 (adjusted for degree of freedom) by adding additional variables.

where

m = direct man-hours per pound of airframe;

N = cumulative number of planes;

Z = other explanatory variables (i.e., lot-size or production-rate, and model-change variables); and

k = number of explanatory variables.

For the AD and A-4, where the flattening effect was incorporated into the regression analysis, Equations (2) and (5) were combined.

The form of Equation (5) is consistent with the practice in the literature, but may represent a misspecification of the form in which some explanatory variables should enter this equation. If the true relationship between cost and production rate or lot size is U-shaped, as the theory suggests, the correct form for the specification of production rate and lot size is "quadratic," as explained in Subsections 2 and 3, below. If production rate or lot size has values that are not close to the optimum production rate or lot size, then Equation (5) gives a correct representation of results over the region of the observed data. Two possible quadratic forms that could be used are $(Z - a)^2$ or (Z and Z^2). However, both these quadratic forms have statistical or mathematical problems. In the first form, $(Z - a)^2$, the form that should be used for a is unknown; in the second form, Z and Z^2, there is a high intercorrelation between Z and Z^2 that makes the estimated values of the Z and Z^2 coefficients unreliable. With the limited quantity of data available, we have used Equation (5) for analysis (rather than attempting to develop a quadratic form whose estimators would have complex statistics associated with them), recognizing that we may be introducing a misspecification error.

As can be seen from Table 2, if cumulative output "explains" almost all the variation in cost, which will be reflected in an R^2 close to 1.0, then additional variables do not add much to "explanation" of cost. However, if the R^2 is not close to 1.0, then additional variables usually add a great deal to the "explanation" of cost. In the case where cost behavior is dominated by cumulative output, it may be that not enough variability occurs in the other independent variables for their effects to show up statistically. If, in addition, these other variables are not at their optimal values, then the entire progress curve would be too high. This inefficiency would not be evident from the estimated progress curve.

1. Effect of Model Change

We need to examine model change at least for the following statistical reason: In order to isolate the effect of production rate and lot size, it is desirable to incorporate within the statistical analysis any other variable that has a significant effect on cost. In the case of aircraft (and probably of many other products), such a variable is model change. It often shows up as improvement of the fit of the regression equation, as indicated by Table 1 and by Appendix A. The typical way in which model change affects the progress curve is shown by Figure 7.

If we measure the distance between the actual progress curve (solid line in Figure 7) and the progress curve projected for no model change (dashed line in Figure 7), then we obtain the shape of the dummy variable required to account for model change (shown by Figure 8).

The curve shown by Figure 8 can be approximated by a "geometrically lagged" dummy variable. To give an example of a geometrically lagged dummy variable, let us suppose the original model is produced for the first 15 lots, but a new model is produced after lot 15. Then the geometrically lagged dummy variable D would be represented by the following values:

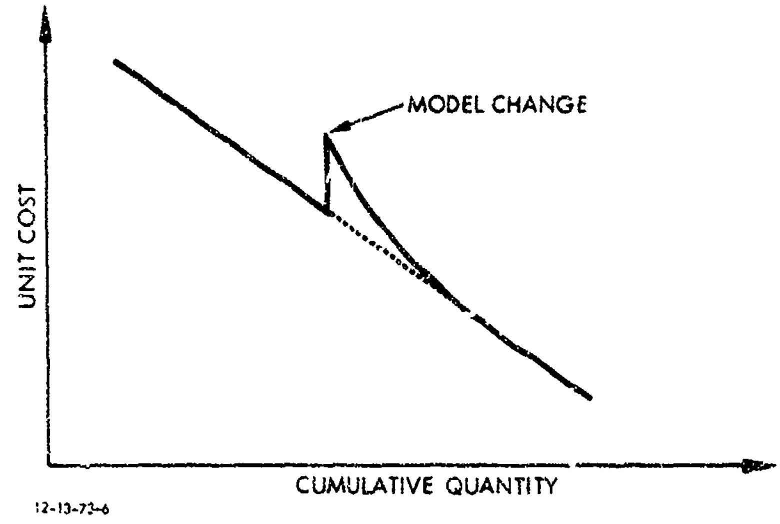


Figure 7. EFFECT OF MODEL CHANGE ON PROGRESS CURVE

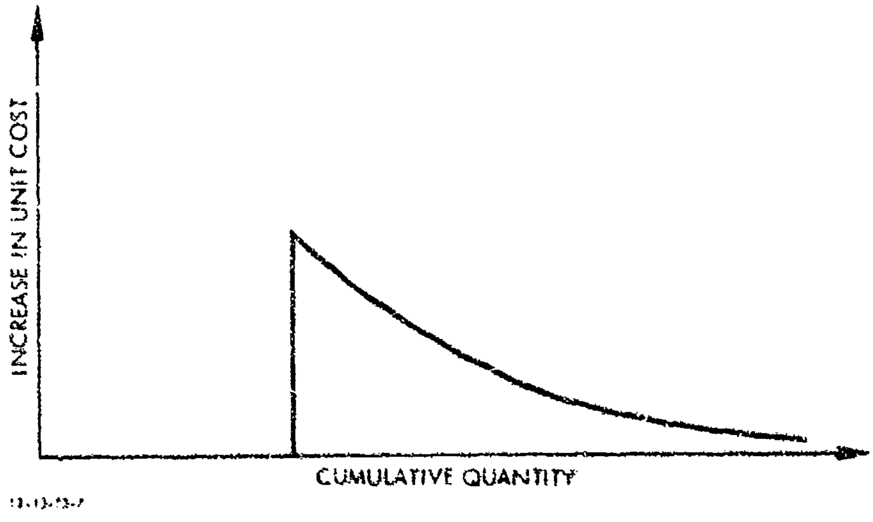


Figure 8. INCREASED IN UNIT COST CAUSED BY MODEL CHANGE

D = 0 for lots 1 through 15
D = 0.5 for lot 16
D = 0.25 for lot 17
D = 0.125 for lot 18
⋮ ⋮
D = 0.0000305 for lot 30.

The rules for obtaining these values are as follows:

(1) The value of D for the first lot with the new model is 0.5.

(2) Each subsequent value of D is one-half the immediately preceding value of D.

If all the values assigned to D were summed up, a value of 1.0 would be obtained. In effect, these weights assume that 50 percent of the increased cost of a model change occurs in the first lot of the new model, 25 percent occurs in the second of these lots, 12.5 percent occurs in the third of these lots, etc.

If the points given for this dummy variable are plotted, and a straight line is connected between each pair of points, then we approximate the curve shown by Figure 8.

Suppose we had two model changes, one at lot 16 and the other at lot 25. Then we would use two geometrically lagged dummy variables.

D1 = 0 for lots 1 through 15
D2 = 0 for lots 1 through 24
D1 = 0.5 for lot 16
D2 = 0.5 for lot 25
D1 = 0.25 for lot 17
D2 = 0.25 for lot 26
⋮ ⋮
D1 = 0.0000076 for lot 32
D2 = 0.0000076 for lot 41.

The form of the equation used to incorporate model change was

$$\ell n\,m = a_1 + b_1 \ell n N + b_2 \ell n Z + \sum_{i=3}^{k} b_i D_i \ , \qquad (6)$$

where

m = direct man-hours per pound of airframe;
N = cumulative number of planes;
D = geometricaly lagged dummy variable for model change;
Z = lot-size or production-rate variable; and
k = number of explanatory variables.

We found that this approach gave a good representation of the effects of model change when most of the variance in price was being explained by the cumulative number produced. However, it did not adequately represent situations in which two or more models were produced simulatneously or in the portion of the progress curve that exceeded the flattening point for the two cases observed, the AD and A-4 aircraft. (See Appendix A for a disucssion of the problems associated with incorporating the model-change variable in the progress curves of the AD and A-4 aircraft.)

2. Effect of Production Rate

A considerable number of empirical studies have been undertaken over the last quarter-century to measure the effects of production rate on cost without reference to the progress-curve concept. A summary of the results of several studies are given by Tables D-1, D-2, and D-3 (see Appendix D). These tables are taken from a survey article by Walters [19]. These results show that average and unit costs may be either falling, constant, or rising. In other words, increasing (or reducing) the production rate may either reduce, leave unaffected, or increase unit cost. These results are not inconsistent with the conventional theoretical[1] relationship between production rate (output per unit of time) and marginal or average cost: variable inputs tend to show first increasing and then diminishing returns when applied to fixed factors (e.g., size of plant or the availability of a skilled work force)--as illustrated in the U-shaped curve of Figure 9. (Appendix E presents a mathematical derivation of the U-shaped unit-cost curve.)

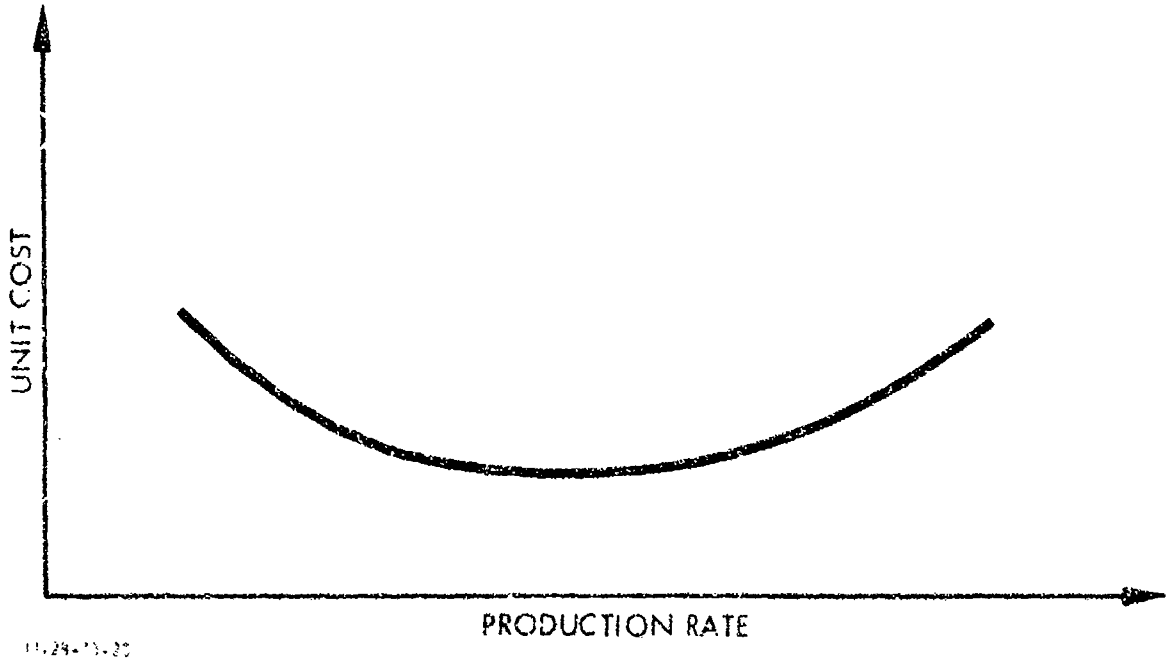


Figure 9. RELATIONSHIP BETWEEN PRODUCTION RATE AND UNIT COST

We now turn to the much more limited empirical work on the effect of production rate on cost within the context of progress curves. Alchian [6], using World War II data [21], tested the following equation:

$$\log m = a + b_1 \log N + b_2 \log \Delta N , \qquad (7)$$

where

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[1] Paul A. Samuelson, Chapters 23-24, *Economics: An Introductory Analysis* [20].

m = direct man-hours per pound of airframe;
N = cumulative number of planes; and
Δ = rate of aircraft production per month.

This equation has rate of production added to the standard log-linear progress-curve formulation. It was tested on 22 "model-facility combinations (MFC)." Examples of MFC tested by Alchian were Boeing B-29, Wichita; North American P-51, Inglewood; and North American P-51, Dallas. His conclusion was that "the results cast doubts on any of the alternatives being better fits than the usual progress curve. The principal reason that little improvement would be expected is the presence of very high correlation among...N [cumulative output] and ΔN [rate]" [6, p. 13].

A study by Hirsch [22] also examined production rate within the context of progress curves. Data consisted of five years' worth of monthly observations on production rate and cost for a single-plant machine-tool manufacturer. Manufacturing was performed by lot. Since lots were initiated on an approximately monthly basis, lot size in this case could be used as a good proxy for production rate. For each type of machine, average direct-labor hours by lot (for machining, assembly, and the total of the two) were regressed against lot size (rate) and cumulative quantity. For the two types of machinery having the greatest variation in rate, it was found that (1) the effect of cumulative quantity was always significant, with negative regression coefficients indicating progress; and (2) the effect of rate never was significant, and the estimating coefficients were both positive and negative.

A study by Preston and Keachie on radar equipment [23] used regression relationships containing both cumulative output and production rate as independent variables. Total cost and labor cost were used as alternate dependent variables. Five of the six regressions that were run had both cumulative output and production rate as significant variables. Production rate was significant at the .05 level, with a consistently negative coefficient. However, from their remark that "from examination of the data, it was determined that the rising phase of the short-run cost curve would not be observed with sufficient frequency to permit estimation" [23, p. 104], it could be surmised that data that would have indicated a positive relationship between production rate and cost were not included in their regressions. If this surmise is correct, then to obtain consistently negative rate-coefficients that are statistically significant is not surprising and does not prove much. However, the results in all these cases are consistent with a U-shaped cost curve.

For several aircraft in the *BACKFILL* files [24], data were available on either monthly shop production or monthly scheduled deliveries of aircraft. Some of these data were not used because of serious interpretive or statistical problems caused by the concurrent production of different models of the same aircraft. We used these data in conjunction with data from the Naval Air Systems Command [7]. Regressions having the same basic form as Alchian's were run:

$$\ln m = a_1 + b_1 \ln N + b_2 \ln X , \qquad (8)$$

where

m = direct man-hours per pound of airframe;
N = cumulative number of planes; and
X = rate of aircraft production per month.

Table 3 gives the coefficients obtained for production rate. A negative coefficient indicates that increasing the production rate will reduce cost, while the converse is true for a positive rate.

From Table 3, we find that three production-rate coefficients are not significant at the .05 level; one is significant

Table 3. EFFECT OF CUMULATIVE QUANTITY AND PRODUCTION RATE ON UNIT COST

Aircraft Model	Progress Curve Coefficient	Progress Curve (Slope)	Production Rate Coefficient	Production Rate (Slope)	Average Monthly Production Rate
B-58	-.488**	(71.3)	-.050*	(96.6)	1.84
B-52H, Wichita	-.231**	(85.2)	-.109	(92.7)	4.34
B-52, Seattle	-.325**	(79.8)	-.022	(98.5)	5.33
B-52, Wichita[a]	-.266**	(83.2)	-.090	(93.9)	6.14
B-52G, Wichita	-.423**	(74.6)	-.065**	(95.6)	7.17
KC-135	-.452**	(73.1)	.134**	(108.9)	8.01

**Statistically significant at the .001 level (two-sided test).

*Statistically significant at the .05 level (two-sided test).

[a] Excluding G and H series.

at the .05 level with a negative sign; and two are significant at the .001 level, but with opposite signs. Since, according to certain theoretical considerations, a U-shaped relationship may exist between unit cost and production rate (see Appendix E), the three not-significant results may be due to the misspecification of the form that the production rate enters into the regression equation. This misspecification also occurs in all the empirical studies we are familiar with. Instead of $\ell n X$, X should enter into the regression with a form such as $(X - a)^2$. However, without some *a priori* information or some special technique, the value of $\underline{a}$ cannot be determined.

To judge the quantitative effect of the production rate, we have presented the production-rate "slope" that corresponds to the rate coefficient. These production-rate slopes initially can be interpreted in the same way as progress-curve slopes. An 80-percent production-rate slope means that if production rate is doubled, unit cost falls by 20 percent. It is evident from the numerical values of the production-rate slope that the quantitative effect of changing the production rate appears to be small.[1]

If the U-shape of the rate relationship holds, these slopes may actually overstate the savings that could be achieved--as is illustrated by Figure 10. If we are at point A on the cost curve, then we could achieve the lowest average cost by moving to point B. However, using the slope derived from the regression equation would indicate point C, which would considerably overstate the amount of cost reduction. If too sharp a change in the right direction occurred in the production rate (e.g., moving from point A to point D), then the average cost at the new rate might be higher than at the old rate. Only if the production rate were far too small (point E) or far too large (point F) would significant cost reduction occur by moving the production rate toward point B.

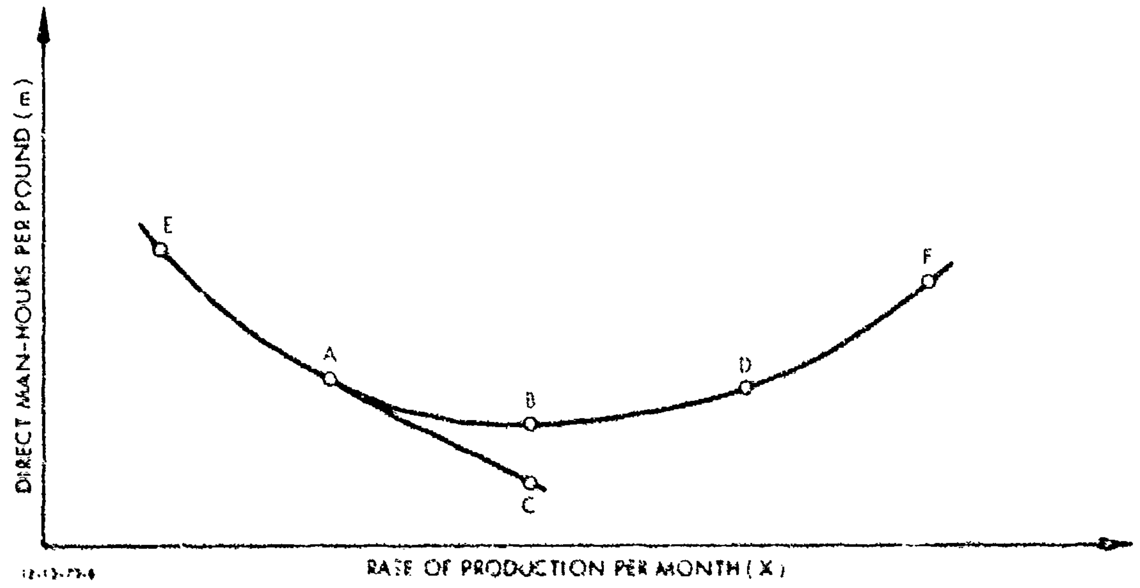

Figure 10. TYPICAL U-SHAPED COST CURVE

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[1] Nevertheless, we must caution that this small quantitative effect could be due to a misspecification of the production-rate variable.

The relationship between U-shaped cost curves and progress curves is shown by Figure 11. (The mathematical relationship is given in Appendix E.)

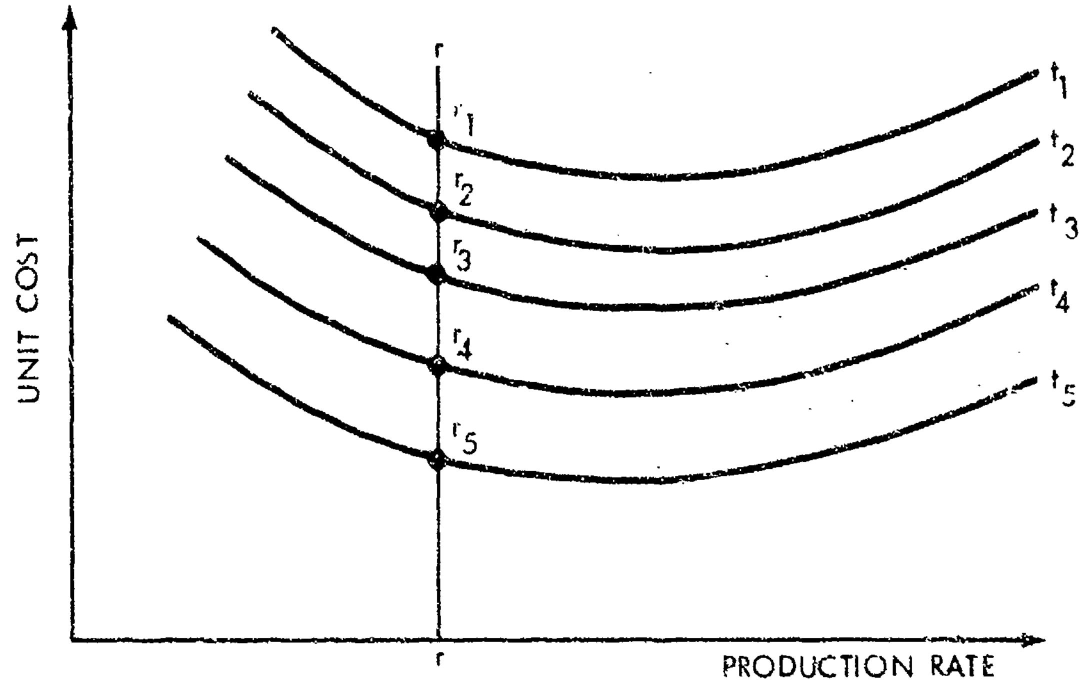

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Figure 11. SHIFT IN U-SHAPED COST CURVES OVER TIME

As Figure 11 illustrates, at any particular time t_i, unit cost is represented by a U-shaped curve. Over time, however, the U-shaped curve is shifted downwards because of "learning." Thus, for any given production rate (rr in Figure 11), unit cost is decreasing over time and therefore is also decreasing as cumulative output is increasing. A typical progress curve results if the unit costs associated with the points r_i are plotted against cumulative output.

3. Effect of Lot Size

"Lot size" is the output obtained from one round of tooling setup. General practice is to schedule tooling setup, fabrication, and assembly by lot size. An annual buy frequently comprises a number of lots. At least in the case of airframes, the lot size appears to have a more important effect on cost than the production rate has. This apparent fact is also likely to be true for other products that are characterized by small lot sizes. Such products usually are expensive, complex, and specialized; and they often undergo considerable technological development. For small lot sizes, setup and other nonrecurring costs related to improvements and any other modifications specific to any given lot can be expected to be an important part of total cost. However, larger lot sizes will spread the costs specific to the lots over more units, thereby reducing the average cost of each unit. In addition, large lots may lead to larger volume buys of parts and components, with a resultant cost reduction. These cost-reduction effects are cited by the limited literature on the relationship of average cost to lot size. For very large lot sizes, however, tooling and machinery begin to wear out--a situation that necessitates increased maintenance and that may interrupt production activity. Inventory costs also increase with lot size. Another effect is the introduction of engineering and product-configuration changes; the larger the lot size the more likely it is that changes will be introduced before the lot is completed. These changes must then be incorporated by a reworking of the parts that have already been produced. Increased tool maintenance, inventory size, and product-configuration change (caused by the volume of Engineering Change Notices) can cause a significant rise in unit cost with large lot sizes. If we combine the two influences of (1) setup cost and (2) costs of tool maintenance, inventory size, and product change, we can expect a U-curved relationship between cost and lot size, similar to the curve found for the production rate.

While occasional mention is made of the effect of lot size on cost, we did not find any statistically rigorous quantitative results in the literature. Therefore, we had to determine the quantitative importance of lot size without reference to the literature.

To determine empirically the effects of lot size on unit cost of airframes, we ran regression equations on 24 aircraft, with both cumulative output and lot size as explanatory variables of unit cost. These regressions had the following basic form:[1]

$$\ell n m = a_1 + b_1 \ell n N + b_2 \ell n S \ , \qquad (9)$$

where

m = direct man-hours per pound of airframe;
N = cumulative number of planes; and
S = lot size.

The results of these runs are shown by Table 4. Despite the overwhelming effect of cumulative output on unit cost, lot-size coefficients were statistically significant for 14 of the 24 aircraft--9 of them at the .001 level.

While some of the 10 not-significant coefficients for lot size appear to be due to a small sample size, as indicated by Table 5, a more likely explanation is that lot size shows up as being an important influence on cost only when cumulative output is sufficiently large, as indicated by fighter, attack, and

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[1] While it is believed that the relationship of lot size and cost is U-shaped, there are serious methodological problems of introducing the lot-size term in any non-log-linear form. The methodological problems and the effect of misspecifying the form of the lot-size term in the regression equations are identical to the misspecification of the production-rate term (previously discussed in Section G.2., above.

Table 4. EFFECT OF CUMULATIVE QUANTITY AND LOT SIZE ON UNIT COST

Aircraft Model	Progress Curve		Lot Size		Average Lot Size
	Coefficient	(Slope)	Coefficient	(Slope)	
C-124	-.054	(96.3)	-.408**	(75.3)	20.3
F-86	-.187**	(87.8)	-.317**	(80.3)	55.2
C-123	-.293**	(81.6)	-.263**	(83.4)	13.7
C-130	-.349**	(78.5)	-.242**	(84.6)	17.3
P-3	-.273**	(82.8)	-.196*	(87.3)	13.5
T-28	-.212**	(86.3)	-.192*	(87.6)	59.8
AD	-.462**	(72.6)	-.181**	(88.2)	39.0
F-100	-.266**	(83.1)	-.168**	(89.0)	55.2
A-4	-.375**	(77.1)	-.072*	(95.1)	42.2
O-1A,B	-.178**	(88.4)	-.056**	(96.2)	22.4
F-2H	-.296**	(81.5)	-.025*	(98.3)	22.5
F-8	-.391**	(76.3)	.093*	(106.3)	32.8
T-33	-.203**	(86.9)	.117**	(107.8)	90.3
F-84	-.423**	(74.6)	.208**	(113.4)	96.0
FJ-2	-.396**	(76.0)	-.118	(92.1)	46.1
A-3	-.434**	(74.0)	-.100	(93.3)	13.4
F-101	-.292**	(81.7)	-.072	(95.1)	26.7
T-37A,B	-.426**	(74.4)	-.052	(96.5)	37.6
F-80	-.418**	(74.9)	-.044	(97.0)	61.6
C-119	-.256**	(83.7)	-.037	(97.5)	22.8
F-94	-.262**	(83.4)	.139	(90.8)	35.8
F-89	-.252**	(84.0)	--[a]	--[a]	28.8
C-82A	-.483**	(71.5)	--[a]	--[a]	15.7
F-3	-.424**	(74.6)	--[a]	--[a]	27.3

**Statistically significant at the .001 level (two-sided test).

*Statistically significant at the .05 level (two-sided test).

[a] Lot size did not add to explanatory power of equation.

trainer aircraft in Table 6. For reasons that are not apparent, this is not the case for other aircraft types.

Table 5. DISTRIBUTION OF SIGNIFICANCE OF COEFFICIENTS BY NUMBER OF LOTS

Coefficient	Number of Models	
	Less than 20 Lots	20 or more Lots
Significant	0	14
Not significant	7	3

Table 6. DISTRIBUTION OF SIGNIFICANCE OF COEFFICIENTS BY CUMULATIVE OUTPUT

Coefficient	Number of Fighter, Attack, and Trainer Models		Number of Cargo, Patrol, and Observation Models	
	Total Output < 1,000	Total Output ≥ 1,000	Total Output < 1,000	Total Output ≥ 1,000
Significant	1	8	4	1
Not significant	7	1	0	2

The results of these regression equations showed that the average lot size for airframes usually was too small; unit costs in most cases could be reduced by increasing the lot size, as illustrated by Table 7. Of the 14 aircraft models shown in this table, the unit cost of 11 of them would be reduced by increasing the lot size. For the 3 aircraft models where unit cost would be increased by increasing the lot size, 2 were being produced in very large lot sizes.

Table 7. RELATIONSHIP BETWEEN AVERAGE LOT SIZE AND UNIT COST

Item	Number of Aircraft Models* with Average Lot Size--	
	Smaller than 60	Larger than 90
Unit Cost Reduced by Increasing Lot Size	11	0
Unit Cost Increased by Increasing Lot Size	1	2

*This table is composed of the 14 aircraft having statistically significant lot-size coefficients.

Chapter IV

COMPETITIVE PROCUREMENT

A. INTRODUCTION

The primary emphasis under this subtask was to measure quantitatively the effect of competition on selling price.

The objectives of competition among suppliers are lower prices charged to the government and improved quality of the products. Because no objective measures of product quality were available, we have restricted ourselves to an examination of price competition. Further, while it was the original intent to examine quantitatively the effect of competition throughout a product's life, the available data precluded our quantitatively examining the effect of competition in all but the reprocurement phase of a program. Therefore, the following analysis is based on and directly applicable to competition introduced during the reprocurement phase of a program. Basically, the reason that data are not available to examine quantitatively the effect of competition in earlier phases of a program is that very few programs had competition beyond the prototype stage, and those that did had no control group by which a comparison could be made to see what the cost might have been if there had not been competition.

Improved quality may incorporate greater reliability, a broader base of technology, and more varied approaches to the weapon-system objectives; but these factors are multidimensional and difficult, if not impossible, to quantify to scalar values without imposing enough subjective value judgments to bias the results completely. Regarding the characteristics of the weapon system as fixed makes the problem of measuring the benefits of competition more tractable, since we are left with prices and costs. Nevertheless, the simplification may ignore substantial benefits of competition, some of which are qualitatively discussed by Schairer [25] and Schlaifer [26]:

The Schairer article [25] presents numerous examples of the qualitative benefits of competition in the aircraft industry. One example that is particularly revelant to this study deals with the development of the Boeing 707 and illustrates the distinction between long-run and short-run costs. In 1955, at the start of the 707 program, Boeing designed a single Boeing 707 that would have maximum commonality with the KC-135 and that would be sold to both domestic and overseas airlines. This cheapest single 707 model had the disadvantage that its range exceeded the needs of domestic airlines and yet was not great enough for all overseas operators. Despite these obvious disadvantages, Boeing proceeded with the development of a single-model airplane until competition was introduced in the form of the DC-8. The competitive pressure forced Boeing to change its plans and develop the 707-120 series and the 707-320 series. While producing two airplanes increased initial cost, it had the beneficial effect of reducing the operating costs of the domestic airlines and overseas airlines 20 percent and 7 percent, respectively--compared to the proposed single-model 707. These reduced operating costs more than offset the higher initial cost, with a resultant long-term cost saving to the traveling public.

Schlaifer [26] cites an example that illustrates how competition may be the only way to achieve some desired results. At the end of World War I, Stromberg-Carlson had a virtual monopoly on carburetors for aircraft engines. The Stromberg-Carlson carburetor used a float control that had a number of serious shortcomings. Yet in the absence of competition, Stromberg-Carlson simply refused all entreaties on the part of the government to design a new type that would be truly suitable for aircraft. However, when the government funded a competitor, Chandler-Groves, to develop a floatless carburetor, Stromberg-Carlson quickly doubled its engineering budget, provided the technical thinking, and produced the pressure carburetor that was the only carburetor used on new high-powered aircraft engines in the United States at the end of the Second World War. To quote the author: "The history of the Stromberg carburetor is thus one of the best possible illustrations of the great need for competition in development."

Before setting out the analysis, it is useful to examine briefly the current procurement cycle for major new systems. For our purposes, the procurement cycle can be thought of as four distinct phases:

- Preliminary design phase
- Development phase
- Initial production phase
- Reprocurement phase.

Under current procurement practices, for the most part, competition exists in the design phase of the program and occasionally in the reprocurement phase of the program; but rarely is there competition in the development or initial production phases. The winner of the design competition usually is awarded a sole-source contract to undertake development. For large systems, because of the high development cost and the generally limited size of the market, losers of the design competition generally drop out of the marketplace for that particular product, in essence giving the winner of the design competition a virtual monopoly. However, as a precondition of winning the design award, the contract signed generally allows the government to have access to cost data on the development and any subsequent sole-source production contracts, along with clauses preventing excess profits. The problem with the present system is that, since the contractor is put in a position in which he must justify all his costs, greater attention may be spent on cost justification than on cost reduction. Further, at the time the design awards are made, many of the problems associated with the development are still unknown. As the problems arise, the government has little recourse but to stick with the original contractor. Thus, while the current contracting procedures generally prevent the winning contractor from making a monopolist's profit, they do not insure that the most efficient producer does the actual work. (See Appendix F for a discussion of efficiency and competition.)

Because the development and production phases of most programs overlap, the contractor who does the development also is awarded a sole-source contract for the initial production.

If the product is relatively simple and there are to be recurring purchases, the government may procure the production drawings and data and introduce competition into the reprocurement phase of the program.

The original intent of the study was to examine quantitatively the price effect of competition throughout the product's procurement life. Unfortunately, the available data precluded examining quantitatively the effect of competition in all but the reprocurement phase of a program. Therefore, the following analysis is based on (and directly applicable to) competition introduced during the reprocurement phase of a program.

Basically, the reason that data are not available to examine quantitatively the effect of competition in earlier phases of a program is that very few programs had competition beyond the prototype stage, and those that did had no control group by which a comparison could be made to see what the cost might have been if there had not been competiton.

B. DEGREE OF COMPETITION EXISTING TODAY

One of the first questions that has to be asked when examining the effect of competition is, How competitive is DoD currently in their procurement? Table 8 is presented to show the degree of competition that presently exists in DoD procurement. As can be seen from the table, the degree of competition has been stable over the recent years, with sole-source procurements accounting for approximately 65 percent; competitively negotiated, 24 percent; and advertised, the most competitive, 11 percent of the dollar value. However, approximately 40 percent of the sole-source awards are follow-ons to contracts that evolved from an earlier design or price competition.

Table 8. PROCUREMENT AWARDS EXCEEDING $10,000
[By percent of total dollars]

Type of Action	Fiscal Year				
	68	69	70	71	72
Sole-source	64.2	65.8	63.0	65.1	67.0
Negotiated*	24.0	23.0	25.2	23.9	22.4
Advertised	11.7	11.3	11.8	11.1	10.6

*Competitively.

A search of the literature on the effect of competition reveals that there are many subjective estimates of the price effect of competition, ranging from 15- to 67-percent savings, but few actual data are presented to support these estimates. Most of the data that do exist were collected as part of the DoD cost-reduction program of the early 1960s. Table 9 presents the form of these data. There are serious shortcomings to the type of data presented in Table 9 (from [27]):

- The data were "selected" to demonstrate cost savings. Thus, they do not necessarily represent an unbiased estimate of the true effect of competition.
- There is no narrative to indicate whether the percent reductions have been corrected for the effects of cost-quantity relationships.

Table 9. EXAMPLES OF EXISTING DATA SHOWING THE SAVINGS RESULTING FROM COMPETITION

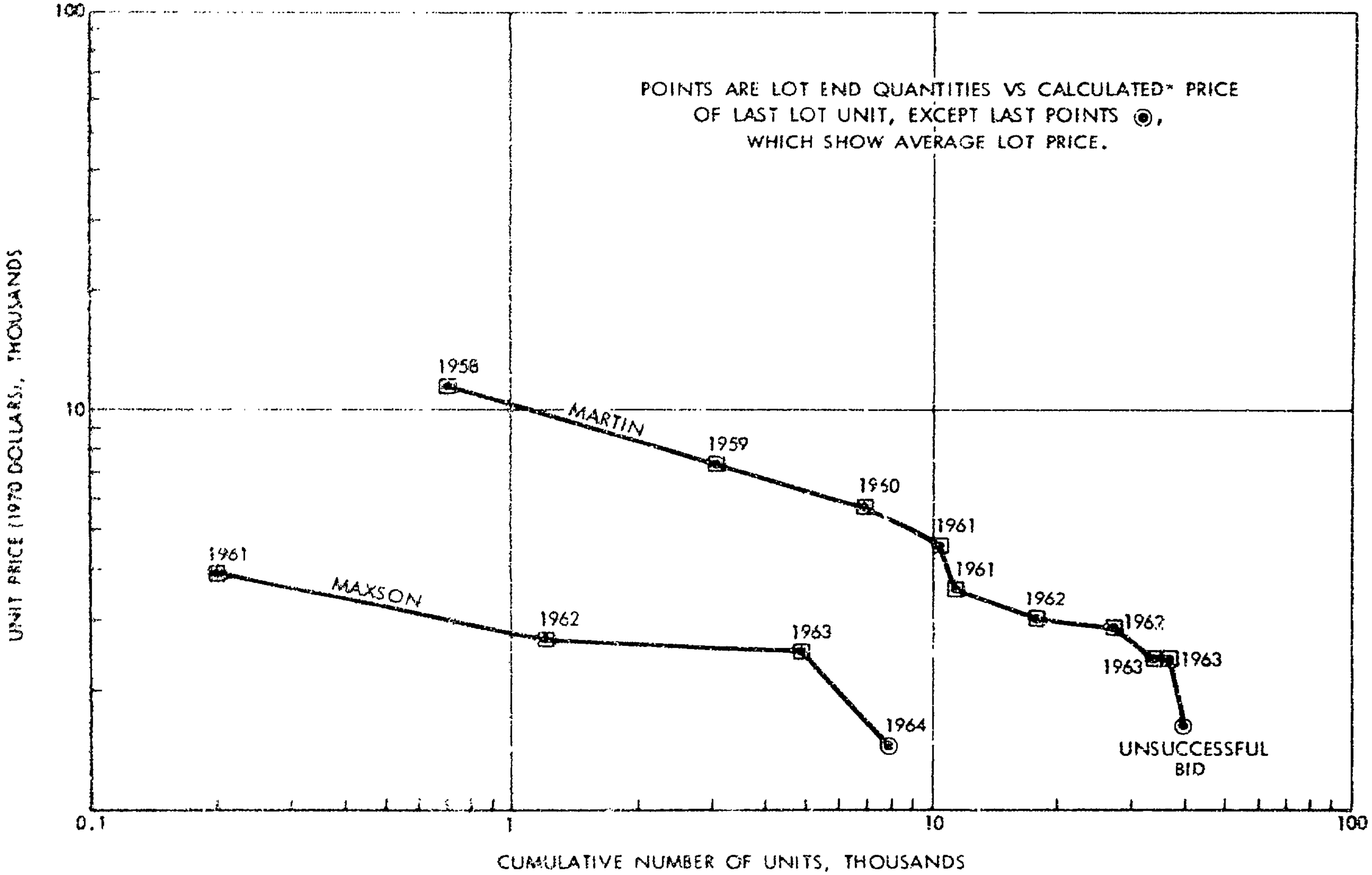
Item	Non-competitive Unit Price (dollars)	Competitive Unit Price (dollars)	Percent Reduction	Savings on Recent Procurement (dollars)
Power Control Box	1.50	1.11	26	214,838
Extendible Earth Anchor	75.43	52.25	30	231,800
Radio Set (AN/PRC-47)	4,370.87	2,797.67	36	1,296,317
R-1051 Receiver	24,473.00	11,750.00	52	4,016,718
Portable Ship Instrumentation Package	795,777.00	595,987.00	25	399,554
Bomb Fuze, M-905, Tail Assembly	18.06	15.14	16	168,797
Power Supply (PP-2058/ULA-26V)	1,238.59	834.10	32	27,118
Shroud, Steering Control Module (SP GAX-5766)	750.00	538.00	28	27,560
Doppler Navigation Radar (AN/APN-153V)	2,924.00	1,567.00	46	4,221,135
Average			32	

Source: *Hearings before the Subcommittee on Federal Procurement and Regulation of The Joint Economic Committee*, Congress of the United States, 89th Congress, 24 January 1966.

C. THE IMPORTANCE OF PROGRESS CURVES IN THE ANALYSIS

Figure 12 presents the cost-quantity history for the guidance, control, and airframe subsystems of the BULLPUP A missile. The BULLPUP A guidance, control, and airframe subsystems were produced from 1958 to 1961 by the Martin Company as a sole source. In 1961, with Martin providing a data package, the subsystems were competitively bid--with the result that Maxson also started to produce the subsystems. From 1961 through 1963, Martin and Maxson competed for a portion of the total award; each was more or less assured that he would get some portion of the award.

While Martin's price dropped significantly between 1958 and 1960, it had nothing to do with competition, which was not introduced until 1961, but was presumably due to a corresponding drop in cost caused by the natural cost-quantity relationship. On the other hand, a significant part of Martin's price drop in 1961 might be attributed to the introduction of competition. Data of the type presented in Table 9 does not provide enough information to separate the natural cost-quantity reductions in price from price reductions caused by the introduction of competition. Attributing all the cost reduction to competition when a program changes from sole-source to competitive procurement can lead to overestimation of the competitive savings. Note in Figure 12 that in 1964 there is another discontinuity in both Martin's and Maxson's progress curves when the competition was intensified by making it winner-take-all. The 1964 point shown for Martin is Martin's unsuccessful bid, while the 1964 point is Maxson's actual price. There is an interesting sidelight to the 1964 BULLPUP history that reflects on some of the hidden costs that may be associated with the intensified competition. Prior to the 1964 award, all the BULLPUPs had a spun nose cone. In order to lower cost in the 1964 winning bid, Maxson replaced the spun nose cone with a clam shell. During



*CALCULATED END-POINT PRICES ARE BASED ON THE ACTUAL TOTAL PRICE OF THE LOT AND THE ASSUMPTION THAT PRICE AND COST ARE CORRELATED.

Figure 12. BULLPUP GUIDANCE, CONTROL, AND AIRFRAME COST HISTORY

a flight, one of the clam-shell nose cones failed and opened. The Air Force grounded all the BULLPUPs with clam-shell nose cones until a fix was made. While Maxson made the fix at their expense, the costs associated with the grounding were, of course, borne by the government and are not shown in Figure 12 or in any of the BULLPUP data used in this report.

D. DATA AVAILABILITY

Since the objective of the study was to measure quantitatively the effects of competition, it was necessary to develop a data base of procurement awards that was both competitive and sole-source and to make comparisons. As mentioned earlier, the design phase of a program is usually quite competitive. The problem of measuring the effects of competition in the design phase is that the only meaningful measures are the results at the end of the development phase. No attempt was made to measure the effects of competition in the design phase, because quantification of results at the end of the development phase is so difficult. An attempt was made to identify and acquire data on systems that had competition during the development and initial production phase of the programs. A few candidate systems were identified, but attempts to obtain quantifiable data were unsuccessful. Thus, the emphasis of the study was to analyze the effects of competition during the reprocurement phase of the program.

An effort was made to assemble a data base of case histories similar to the BULLPUP price history. Four simple criteria were established to identify systems for which data might be sought for analysis of the effect of competition in the reprocurement process. The four requirements were--

- *Retrievable price data.* Price data for many systems no longer being actively procured have been irretrievably lost.
- *At least two sole-source production awards.* In order to establish a sole-source progress curve, it was necessary that data from at least two successive production buys be available.

- *At least one competitive award.* In order to determine the benefits of competition, the data from at least one competitive buy were needed.
- *Unit cost of at least $1,000* to avoid biasing the data base with inconsequential items, since the results should be applicable to more major weapon systems.

The original plan was to identify all systems meeting these simple criteria and to select a random sample for further analysis. It was found impossible to identify all the procurements that went from sole-source to competitive. Records that would allow the tracking of procurement from contract to contract are not usually maintained. This lack of formal procurement history by specific products necessitated the surveying of procurement activities in order to identify systems meeting the above criteria.

Before going further, two caveats should be mentioned about the data. One is that relying on the memory of procurement personnel probably introduces a bias into the data. Personnel were likely to remember their successful procurements more than their unsuccessful. Secondly, since all the programs in the data base were changed from sole-source to competitive procurement, the changes involved a decision that a substantial price reduction could probably be obtained by "going competitive." Therefore, the analysis of this data base may overstate the expected savings that might be achieved by changing to competitive procurement any system currently procured sole-source and selected at random.

Despite the extensive survey taken to identify a large number of systems meeting the above criteria, only 19 systems were so identified.[1]

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[1] See Appendix G for a detailed list of procurement activities contacted in an effort to identify systems eligible for inclusion in the competitive data base.

While progress theory is based on a relationship between *cost* and quantity, it was found that the only data available to us were *price* data. Under a sole-source contract, where the government is monitoring the contractor's costs, marginal costs and marginal prices are highly correlated; and it is expected that progress theory will accurately reflect price behavior. Therefore, we have referred to the sole-source price-quantity relationships as progress curves. Under a competitive contract, where the government is not necessarily monitoring costs, the marginal cost and marginal prices may not be correlated. The significance of this fact will be explored in Section F of this chapter. However, for notational ease, we have referred to the price-quantity relationship after the introduction of competition as the post-competitive progress curve.

E. SAVINGS ON FIRST COMPETITIVE BUY

Table 10 presents a brief summary of the procurement histories of 19 systems.[1] The second and third columns present the sole-source[2] first-unit cost and progress-curve exponent, which completely specify the log-linear progress curve. The fourth column presents the cumulative number of units that were procured under all the sole-source contracts. The fifth column presents the number of units contracted for under the first competitive award. The sixth column lists the estimated savings on the first competitive award; this value was calculated using Equation (10a):

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[1] See Appendix H for a detailed discussion and listing of the data collected for each of these systems, in addition to a number of systems that were originally identified as being potential candidates for the data base but, for reasons discussed in Appendix H, were not included.

[2] The TOW and the second BULLPUP procurement data shown in Table 19 differ from the other Table 10 data in one important respect. The TOW was procured as a dual-source procurement from the very start of production. Thus, it was not possible to measure the price benefits of having (continued on p. 57)

Table 10. SYSTEMS WITH A SUMMARY OF CHARACTERISTICS MAKING UP COMPETITIVE DATA BASE

System	Sole-Source First-Unit Cost (thousand dollars)	Sole-Source Progress-Curve Exponent[a]	Number of Sole-Source Units	Size of First Competitive Award	Savings of First Competitive Award (percent)[b]	Number of Bidders, First Competitive Award
BULLPUP (Martin)[c]	122	-.249	10,195	1,278	13.9	6
BULLPUP (Maxson)[d]	10	-.149	4,438	3,580	45.8	2
TALOS G&C Unit	1,200	-.275	1,605	470	42.3	4
TD-660 Multiplexer	239	-.496	2,175	425	30.2	3
FD-352 Multiplexer	16	-.062	1,383	2,218	57.8	6
TD-202 Radio Combiner	29	-.272	1,057	2,185	52.5	6
TD-204 Cable Combiner	32	-.248	2,687	2,687	50.2	6
HAWK MMMP	56	-.432	8,128	2,346	6.4	4
APX-72 Airborne Transponder	66	-.343	13,250	3,373	32.6	27
MK-48 Warhead	34	-.171	552	480	53.2	8
MK-48 Electrical Assembly	78	-.311	617	417	37.5	8
Aerno 60-6402	11	-.063	535	39	57.0	2
SPA-25 Radar Indicator	272	-.460	1,631	323	21.3	--[e]
SHILLELAGH Missile[c]	153	-.395	1,393	21,512	-0.2	9
ROCKEYE Bomb[c]	33	-.263	35,855	32,087	5.3	12
TOW Missile[d]	16	.135	24,750	12,000	48.1	4
USM-181 Telephone Test Set	5	-.285	342	357	36.0	10
FGC-20 Teletype Set	5	-.044	1,704	276	32.0	3
MD-522 Modulator-Demodulator	18	-.220	2,542	697	60.3	18
CV-1548 Signal Converter	37	-.275	3,945	7,638	53.7	26
Average	122	-.263	5,964	4,719	36.8	8.4
Standard Deviation	265	.131	9,179	8,269	18.5	6.3

[a] These are the sole-source progress-curve characteristics except for the TOW and the second BULLPUP case. For both the TOW and the second BULLPUP case, there had been a series of dual-source procurements. This represents the dual-source progress curves of the source that won the winner-take-all competition.

[b] Except for the second BULLPUP case and the TOW, this is the savings on the first competitive buy. For the second BULLPUP case and the TOW, this is the savings on the first winner-take-all award.

[c] Competitive award split between two producers.

[d] Point at which award made winner-take-all.

[e] Unknown.

$$\text{Savings} = \frac{E - A}{E} \times 100 \,, \qquad (10a)$$

where

Savings = the percent savings realized on the first competitive procurement;

E = the estimated cost of buying the units bought under the first competitive contract as an extension of the sole-source progress curve; and

A = the actual cost of the first competitive award.

For example, in the BULLPUP case the first competitive award was for 1,278 units, of which Maxson built 200 and Martin built 1,078. The actual price charged for these 1,278 units was \$5.26 million. Yet if the 1,278 units were an add-on to the 10,195 sole-source units already built by Martin and the sole-source progress curve were extrapolated, it is estimated that the cost would have been \$6.11 million. Accordingly, the savings were

$$\frac{\$6.11 - \$5.26}{\$6.11} \times 100 = 13.9\% \;.$$

Table 10 shows that the arithmetic average saving of the first competitive reprocurement buy was 37.5 percent. There was, however, a very large dispersion but a symmetrical distribution about the average, with a median of 37.5, a high of 60.3 percent, a low of -0.23 percent, and a standard deviation

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(cont'd) two sources. What was possible to measure was the price changes that occurred when the dual-source procurement was shifted to a winner-take-all competitive procurement. All the characteristics for the TOW progress curve shown in Table 10 pertain to the winning contractor of the winner-take-all competition. The method for procuring the BULLPUP went from a sole-source procurement to a dual-source procurement to a winner-take-all procurement. The first set of BULLPUP data are for the case where the BULLPUP went from a sole-source to a dual-source procurement. The second set of data pertain to the point where the BULLPUP procurement went to winner-take-all and represent Maxson's pre-winner-take-all progress curve.

of 18.9. A regression analysis was performed on the data in order to try to identify some of the factors that would correlate with the cost savings. A regression equation relating the actual cost of the first competitive buy to the number of other parameters was derived as shown by Equation (10b). Because we find no *a priori* knowledge of what form the equation should take, we assumed the most simple form, a basic linear equation where each component of the equation merely arithmetically adds to (or subtracts from) the total. The exact form of the equation was dictated by the fact that it was our desire to come up ultimately with an equation of the form of Equation (10c). While Equation (10c) is not a direct regression equation, it is an arithmetic manipulation of the regression equation and presents the expected cost savings on a percentage basis for the first contract that has had the intensity of the competition increased as a function of the parameters shown.

$$A = 0.383E - 0.732E \times L_1 + 0.926 \times E \times \frac{N_2'}{N_2} + 0.018 \times E \times \frac{N_2}{N_1} \qquad (10b)$$

$$\frac{E - A}{E} = 0.635 + 0.785 \times L_1 - 0.897 \times \frac{N_2'}{N_2} - 0.018 \times \frac{N_2}{N_1}\ , \qquad (10c)$$

where

A = the price paid by the government for the first significant competitive award;

E = the estimated cost of the first competitive award calculated from an extrapolation of the sole-source progress curve;

L_1 = the progress-curve exponent of the sole-source progress curve;

N_1 = the number of units that were built under a sole-source contract before competition was introduced;

N_2 = the size of the first competitive award in units; and

N_2' = the size of the award to the smaller of the two contractors in the case of a split competition (where there is only one contractor winning the award, N_2' is zero).

All the coefficients of Equation (10b), which explains 96 percent of the variation in the price of the first competitive award, are significant at the .05 level. It should be noted that the basic linear regression model requires that the variance be constant over the range of the data. Undoubtedly, in the case of our data, the more expensive the award the greater the variance was likely to be. To compensate for this, Equation (10b) is a weighted linear regression with each observation weighted by $1/F^2$. It is believed that once all the data points are weighted by this factor, the assumption of homoskedasticity required for the linear regression model is met.

From Equation (10c), it can be seen that the expected cost savings on the first competitive award are correlated with--

- *The sole-source progress-curve slope.* The steeper the progress-curve slope the less that is likely to be saved.
- *The type of competition.* Maximum savings are achieved on the first competitive buy on a winner-take-all competition. If, however, there are additional buys after the first competitive buy, then a winner-take-all strategy may not be optimum. The minimum expected savings occurs when each competitor captures 50 percent of the award.
- *The relative size of the first competitive award.* The percentage cost savings are negatively correlated with the ratio of the number of units bought under the first competitive award to the total number of units produced under all the sole-source awards. Although this term was statistically significant, it was not quantitatively too important in predicting the savings for the first competitive buy because of the small size of the coefficient. However, for a series of competitive buys, this term can become quantitatively significant. (See Section F, below, on the behavior of the post-competitive progress curve.)

Surprisingly, one variable that does measure the intensity of the competition was not found to be statistically significant--namely, the number of bidders.

It was also observed that of the 17 winner-take-all competitions in the data base only one was won by the sole-source producer.

The empirical data present a paradox. As opposed to what we observed, logic would suggest that, because of the progress curve, the sole-source producer should have a great competitive advantage in any winner-take-all competition and should win most often.

A number of reasons have been advanced to explain why the sole-source producer in our data base won so infrequently. Reference to Figure 13, which is a conceptual description of the data we observed, helps to illustrate the arguments. Let us define the most efficient progress curve as a cost-quantity relationship such that for any quantity no producer could ever have costs lower than the costs represented by the most efficient progress curve (illustrated by Curve 1). Presumably, an ideal procurement environment would force producers to be as efficient as possible and would lead to the selection of producers with the most efficient progress curves. Curves 2 and 3 are meant to represent symbolically all the other possible progress curves (less efficient than the most efficient progress curve) that could be followed.

If a sole-source producer were following the most efficient progress curve, except for either the case where this producer was making excess profits (generally precluded in a sole-source contract under the Armed Services Procurement Regulations) or the case of a "buy-in" by a competitor, there would be neither much likelihood of achieving significant savings by introducing competition nor much chance of the sole-source producer's losing the competition. On the other hand, if the sole-source producer were following an inefficient progress curve (2 or 3), there is a significant opportunity for price reduction by introducing competition, since the competition would allow some other producer (who might follow a more efficient progress curve) either to bid on the product and win the competition or to force the sole-source producer to a more efficient progress curve. There

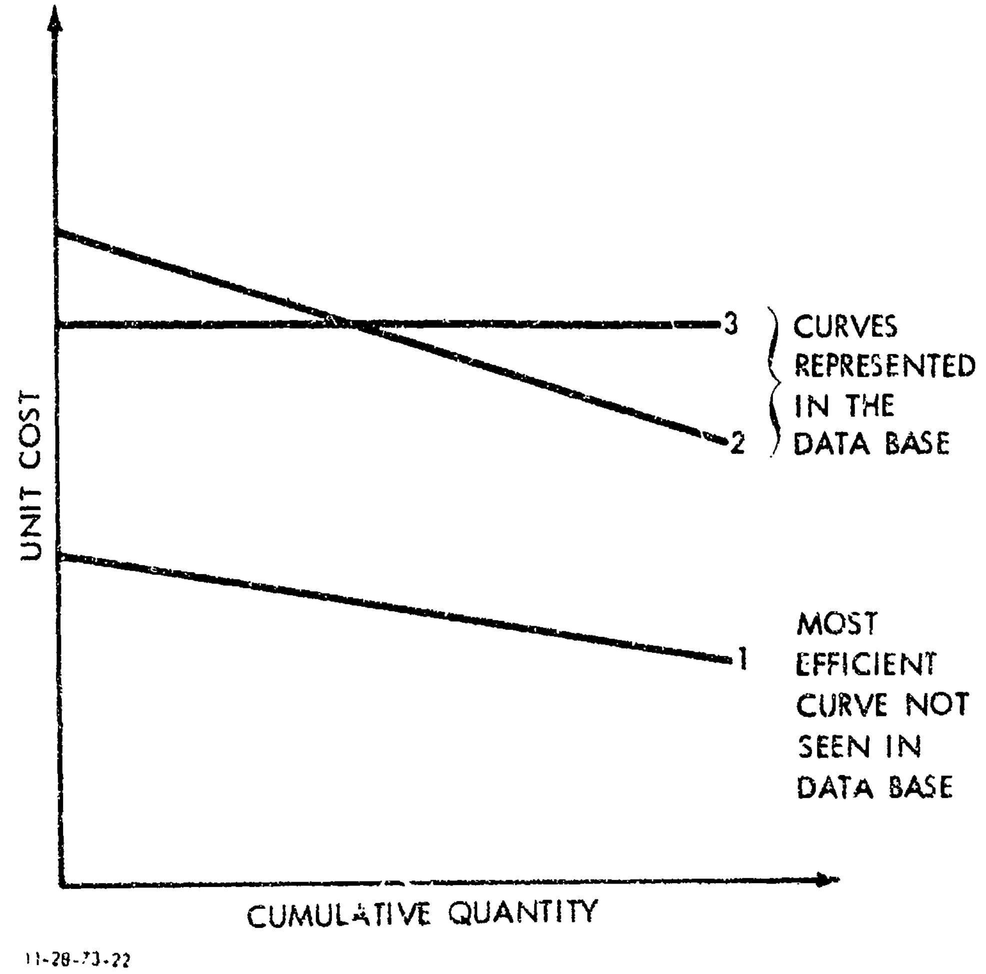

Figure 13. ALTERNATIVE COST-QUANTITY CURVES

are some institutional reasons that may make it difficult for the sole-source producer following an inefficient progress curve to shift to a more efficient progress curve. These institutional reasons, which would mitigate against the changes that the sole-source producer must make in his cost structure if he is to win the competition, may more than offset the sole-source producer's advantage in being experienced in the production of the product. Since the savings achieved by introducing competition exceeded 10 percent for all but three cases in our data base (and only one of these was a winner-take-all), it would appear that the most efficient progress curve was seldom, if ever, observed. The fact that our data base was composed mainly of products following progress curves that were not the most efficient, combined with the institutional difficulty of changing an established production procedure (with attendant costs), goes a long way to explain why the winning of the competition by the sole-source producer was so infrequently observed.

Referring again to Figure 13, it is obvious that for some quantity produced the potential savings that can be achieved by shifting from an inefficient progress curve to the most efficient progress curve will be greater for products following an inefficient flat progress curve than for products following an inefficient steep progress curve. This is exactly what our derived regression equations for savings predict.

Before leaving this section, an important caveat should be restated. Our data base was not a random selection of all systems being procured sole-source. In order to enter our data base, the system had to be competed at least once. Therefore, someone had to make the conscious decision that it was technically possible to compete the system and that the potential savings from competition more than offset the costs associated with developing the necessary data to run the competition. Thus, the regression equations we have derived to predict the savings that might be achieved when competition is introduced may not yield unbiased estimators for predicting the savings that might be achieved when competition is introduced into any sole-source procurement chosen at random.

F. POST-COMPETITIVE PRICE-QUANTITY CURVE BEHAVIOR

In order to determine what happens to the progress curve after the introduction of competition, 14 post-competitive progress curves were developed from systems in the data base that had at least one additional procurement after the first competitive procurement. It was necessary to have at least one additional procurement after the first competition in order to develop a post-competitive progress curve. Of the 14 post-competitive progress curves, 6 were for the case where bidders received percentages of the total award, 5 were competitive winner-take-all in subsequent buys, and 3 were sole-source awards to the winner of the first competition. In addition, the only data available to us were price data (rather than cost data), forcing us to deal with post-competitive price curves, which might not have the same slope as the underlying cost curve. The implications of having price data rather than cost data will be discussed more fully in Section F of this chapter.

In deriving post-competitive progress curves for some of the systems, a problem arises that does not arise in deriving sole-source progress curves. The problem is determining what cumulative quantity should be used as the starting point for the progress curve. If the winner of the competition has been the sole-source producer, there is no ambiguity in selecting the quantity against which to start plotting the post-competitive contract prices. The quantity is just a continuation of sole-source cumulative units. However, if the producer that wins the competition is a new producer, there is some ambiguity as to where his progress curve should be started. On the one hand, conventional practice in deriving progress curves is to plot cost versus cumulative quantity built by a given producer. This practice would suggest that the new producer's quantity should start at unit 1. However, in the case of a second-source producer, who may have been supplied drawings and even working models, there is a particularly large ambiguity as to where to start his progress curve.

Ideally, if enough data existed, a nonlinear regression equation could be derived that would estimate not only the intercept and the slope but also the starting quantity.

Unfortunately, we did not have enough data to do this. What was done, instead, was to construct post-competitive progress curves for new producers under two different assumptions: (1) the starting unit was unit 1; (2) the starting unit was the cumulative number of units produced by the sole-source producer. Table 11 presents the results of this comparison for the 11 systems. As can be seen from Table 11, the effect of starting the progress curve at the point where the sole-source producer left off is to accentuate the slope of the post-competitive progress curve. Four of the 10 systems--BULLPUP, ROCKEYE, HAWK, and Aerno 60-6402, whose slopes were derived by starting at the point where the sole-source producer was at the time of the first competition--can be rejected because they are well outside the range of progress-curve slopes that are commonly observed. The slope of a fifth system (the TD-202) is so flat that it makes no difference where the starting point is taken. With 4 of the 10 curves giving implausible results when they are plotted starting at the point where the sole-source producer left off, there is a strong indication that the starting point must be some number significantly less than the point where the sole-source producer left off.

Further, there is strong evidence that the post-competitive progress curve will have a slope that is flatter than the sole-source progress curve. As can be seen from Table 11, 10 of the 14 post-competitive progress curves have slopes that are as flat or flatter than the sole-source progress curves, even when the post-competitive progress curves are derived starting at the point when competition was introduced. In addition, the statistically significant negative sign on the coefficient associated with the size of the first competitive award shown in Equation (10c) is confirmation that the post-competitive progress curve is flatter than the sole-source progress curve. It should be noted that Equation (10c), as opposed to Table 11, was derived from a data base that required no assumption about where the

Table 11. COMPARISON OF POST-COMPETITIVE PROGRESS-CURVE SLOPES
[In percent]

System	Sole-Source Progress-Curve Slope	Post-Competitive Progress-Curve Slope Starting at Unit 1	Post-Competitive Progress-Curve Slope Starting at the Cumulative Number Produced at the Point of Competition
BULLPUP (Martin)	78.5	--*	79.9
BULLPUP (Maxson)	78.5	90.2	39.5
TD-660 Multiplexer	70.9	96.6	78.9
TD-352 Multiplexer	95.3	97.3	93.4
TD-202 Radio Combiner	87.4	99.8	99.6
TD-204 Cable Combiner	84.1	95.9	91.5
HAWK MMMP	74.1	90.9	61.1
APX-72 Airborne Transponder	78.8	96.3	77.3
Aerno 60-6402	95.7	103.7	161.5
SHILLELAGH Missile (Philco)	76.0	--*	76.0
SHILLELAGH Missile (Martin)	76.0	90.1	84.9
ROCKEYE Bomb (Honeywell)	83.3	--*	83.4
ROCKEYE Bomb (Marquardt)	83.3	100.8	110.8
TOW Missile	91.6	--*	100.9

*Does not start at Unit 1 because follows units produced by same contractor under sole-source procurement.

post-competitive progress curve started and that was larger than the data base used in conjunction with Table 11. If the post-competitive progress curve were either as steep as or steeper than the sole-source progress curve, then we would expect the coefficient associated with the size of the first competitive award shown in Equation (10c) either to be insignificant or to have a positive sign, respectively. The negative sign means that the larger the post-competitive award the smaller the percentage savings.

A corollary of the post-competitive progress curves' flatter slope is that it will have a lower intercept (first-unit cost) than the sole-source progress curve.

Detailed theoretical arguments have been developed in Appendix F for both the competitive cost and price curves having lower intercepts and flatter slopes than the sole-source progress curve. These arguments take into consideration such concepts as the producer's efficiency, including the effect of the Armed Services Procurement Regulation (ASPR) profit guidelines, and the likely shift in pricing strategies as the type of contract award shifts from sole-source to competitive.

Our main interest in this section is the behavior of the post-competitive price-quantity curve; therefore, we have briefly summarized below the major argument (which is based on a competitive pricing strategy) about why the post-competitive price-quantity curve should have a lower intercept and flatter slope than the sole-source progress curve:

> On the one hand, during the sole-source procurement, DoD forces the sole-source producer to lower his price as he proceeds down the cost-progress curve. On the other hand, in a competitive procurement (where the emphasis is on price rather than on cost), the competitive producer has an incentive to establish a price that is sufficiently low to capture the market. However, once the market is captured, he has no further incentive or DoD requirement to lower the price more than is necessary to maintain the market, regardless of how his costs decline. In the case of the limited market for specialized DoD products, where there is a winner-take-all competition, there is little incentive for the winner of the first competitive award to lower his price significantly on the second competition, since he knows that none of the losing competitors of the first competition were able to lower their costs through the progress-curve phenomenon; and, hence, the losers' second-round competitive bids are not likely to be much lower than their first-round competitive bids. The flatter competitive price-curve is quite consistent with what is sometimes observed for certain products (particularly vehicles) in the commercial (competitive) marketplace, where the product prices follow an essentially flat price-quantity curve over relatively large production quantities.

Figure 14 illustrates the relationship between the sole-source progress curve and the post-competitive progress curve--namely, that the post-competitive curve has a flatter slope and a lower first-unit cost. The point of immediate interest in

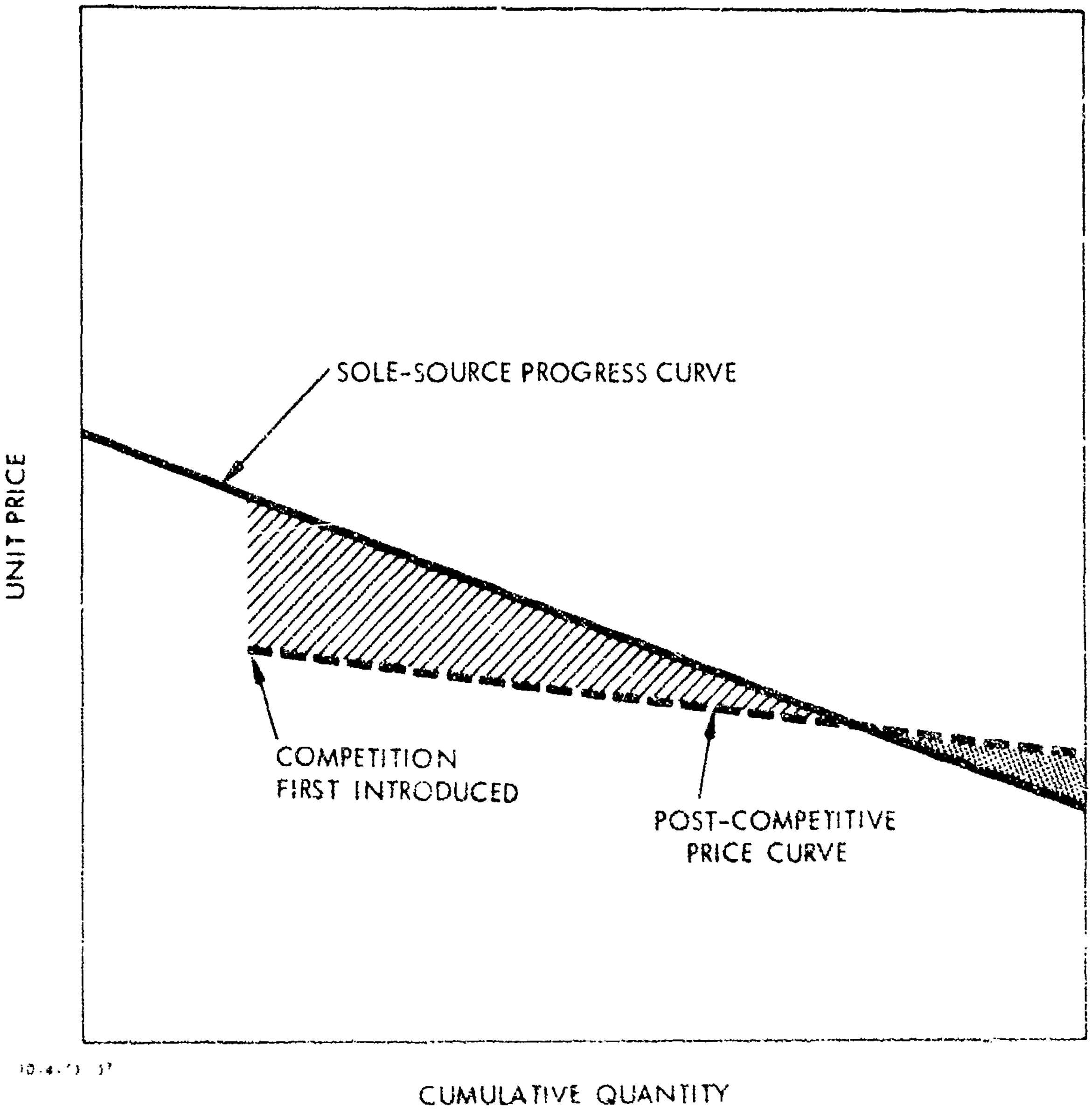

Figure 14. POST-COMPETITION PROGRESS-CURVE MODEL

Figure 14 is that the two curves may actually intersect. It is apparent from the geometry of Figure 14 that the number of units that must be produced before the intersection point occurs, if one exists, is dependent on the number of units that have been produced before competition is introduced, and the degree at which the post-competitive curve flattens out.

In order to examine parametrically the number of cumulative units that must be produced before an intersection point might be expected to occur, it is necessary to derive equations that could be used to predict the post-competitive progress-curve slope and intercept.

The procedure used to develop estimators of the post-competitive progress-curve slope and intercept (first-unit cost) are as follows: A regression equation was derived from the 11 post-competitive progress-curve slope data shown in Table 11 under the assumption that a new producer's post-competitive progress curve starts at unit 1.

Equation (11a) presents the equation that was derived from the slope data:

$$L_2 = 0.220L_1 - 0.221P - 0.064S + 2.64 \times 10^{-6}N_1 , \qquad (11a)$$

where

L_2 = the post-competitive progress-curve exponent;

L_1 = the sole-source progress-curve exponent;

P = a dummy variable (it is 1 if the post-competitive curve is for the producer who was the sole-source producer; otherwise, it is 0);

S = a dummy variable (it is 0 if the competition was a winner-take-all; if not, it is 1); and

N_1 = the cumulative number of units built under the sole-source contracts.

Equation (11a) explains 89 percent of the variance in L_2, with all the coefficients significant at the .01 level. A first-order approximation of the effect that the number of units built by a sole-source producer has on the estimated slope of a second-source's progress curve under the assumption that the second-source's progress curve starts at unit 1 is given by the coefficient on N_1 in Equation (11a). While the term is statistically significant and shows what we would expect (that the larger N_1 is, the flatter the estimated sole-source progress curve would be--under the assumption that the curve starts at unit 1), it is not too significant quantitatively.

Equation (11b) presents the equation that was derived from the intercept data of Table 12.

$$F_2 = 0.833 \times F_1 \times P + 0.463 \times N_1^{L_1} \times F_1 \ . \qquad (11b)$$

$$\frac{F_1 - F_2}{F_1} = 1 - 0.833P - 0.463N_1^{L_1} \ , \qquad (11c)$$

where

F_2 = the post-competitive progress-curve intercept (first-unit cost);

F_1 = the sole-source progress-curve intercept;

P = a dummy variable (it is 1 if the post-competitive award producer was also the sole-source producer; otherwise, 0);

N_1 = the cumulative number of sole-source units produced; and

L_1 = the sole-source progress-curve exponent.

Equation (11b), which is a weighted regression with each observation weighted by $1/F_2^2$, explains 95 percent of the variation in the post-competitive progress curve's first-unit cost. It should be noted that because the same data were used to derive Equations (11a) and (11b) they are potentially correlated. However, their residuals have a correlation coefficient of only 0.13. Equation (11c) is merely Equation (11b) algebraically transformed so that the percentage reduction in the first-unit cost may be calculated directly.

G. IMPLICATIONS OF THE CHARACTERIZATION OF THE POST-COMPETITIVE COST CURVE

Returning to Figure 14, let us examine the implications of the post-competitive progress curve's having a lower intercept and a flatter slope. The flattening out of the post-competitive progress curve raises the question of what happens when the sole-source and competitive curves intersect: Does the competitive curve turn down and follow the sole-source curve, or does it remain flat and cross over? If it does cross over, then all points on the right side of the intersection represent higher prices due to competition. The derived regression equations for the post-competitive progress-curve slope and intercept can be used to examine parametrically for what quantities the intersection is expected. The mathematics are such that the intersection point is very sensitive to the sole-source progress-curve slope and to the point at which competition is introduced. Figure 15 shows this relationship. It can be seen from Figure 15 that for most reprocurement situations the question of whether the two curves cross over or merely intersect is academic, since the point of intersection occurs at quantities far in excess of the normal procurement quantities of major systems. Further, it should be noted that the effect, if any, of starting the post-competitive progress curves of the second-source producer in our data base at unit 1 will bias the estimation of the post-competitive progress-curve slope. The actual slope should be equal to or steeper than the estimated slope. If the actual slope is steeper than the estimated slope, Figure 15 will understate the point of intersection.

Although the question of whether the curves merely intersect or cross over is academic for most reprocurement situations, the fact that the progress curve does flatten has the following important implications: (1) there is a limit to the amount of savings from competition, no matter how large the procurement will be, and (2) savings (from what would be expected to be paid

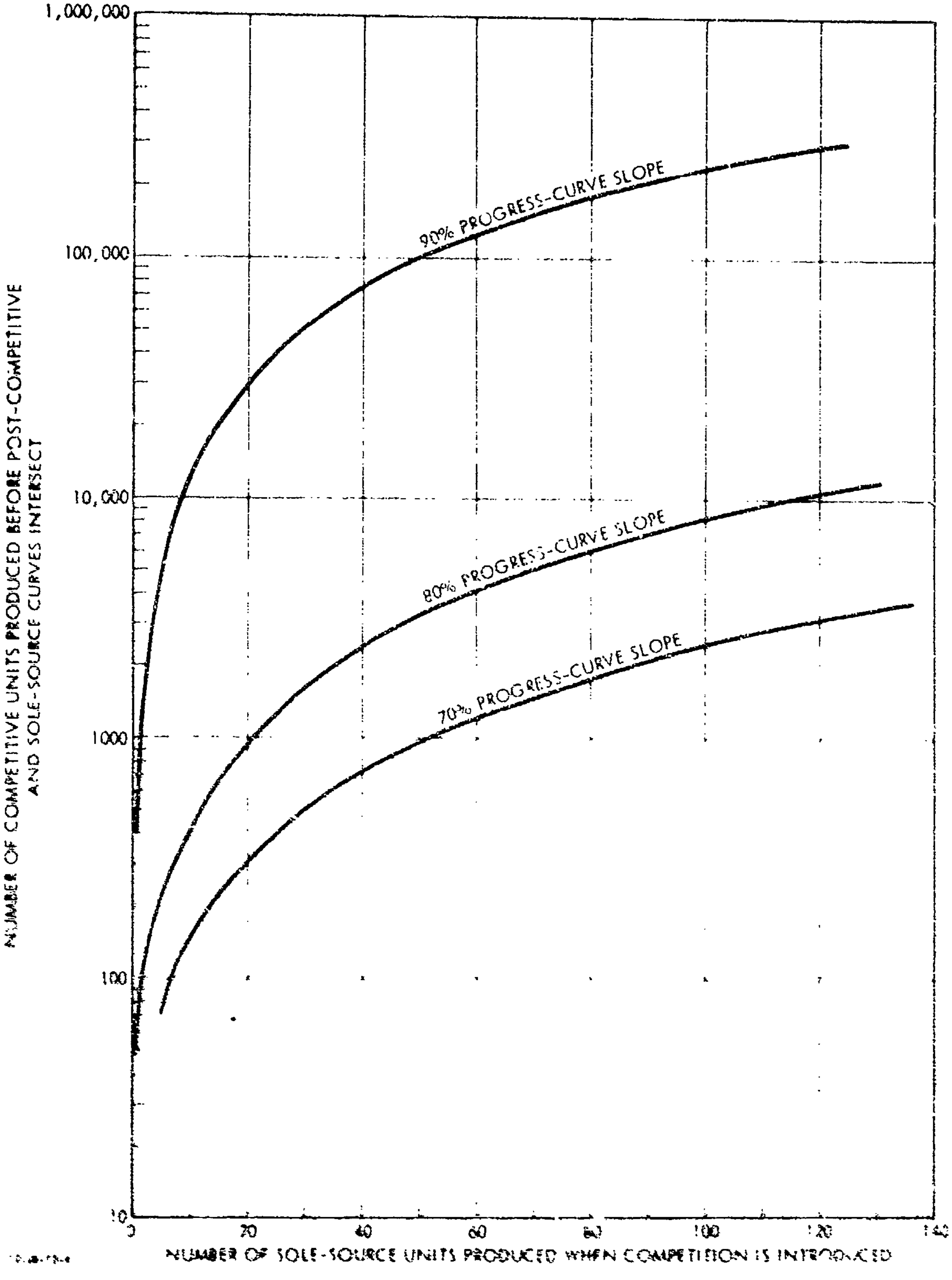

Figure 15. SOLE-SOURCE POST-COMPETITIVE PROGRESS CURVE INTERSECTION VERSUS QUANTITY PRODUCED WHEN COMPETITION IS INTRODUCED

if the sole-source progress curve were extrapolated), measured in percentage terms, decrease with each successive post-competitive procurement. It might be noted in passing that the cost savings from the second competitive buy averaged one percent less than the savings achieved on the first competitive buy.

Figure 16 is presented as a sidelight to the analysis. It shows that because of the progress-curve effects, the positive effects of a continuing dual-source competition may be diminished for systems with steep progress-curve slopes. When the competition is split between two contractors, each producer will produce fewer units and be further up on his progress curve. The additional cost that will be incurred by having two producers produce a combined total of N units, compared to the cost incurred by a single producer producing the N units, is shown in Figure 16 as a function of the progress curve and the proportion of the units made by the smaller of the two producers. Figure 16 is based on the assumption that both producers are efficient and follow the same progress curve. Note that Figure 16 represents cost and not price. It is possible that with the pressure of competition the producers may take a lesser profit and reduce their prices. Or, in the absence of competition, they might not be on as efficient a progress curve.

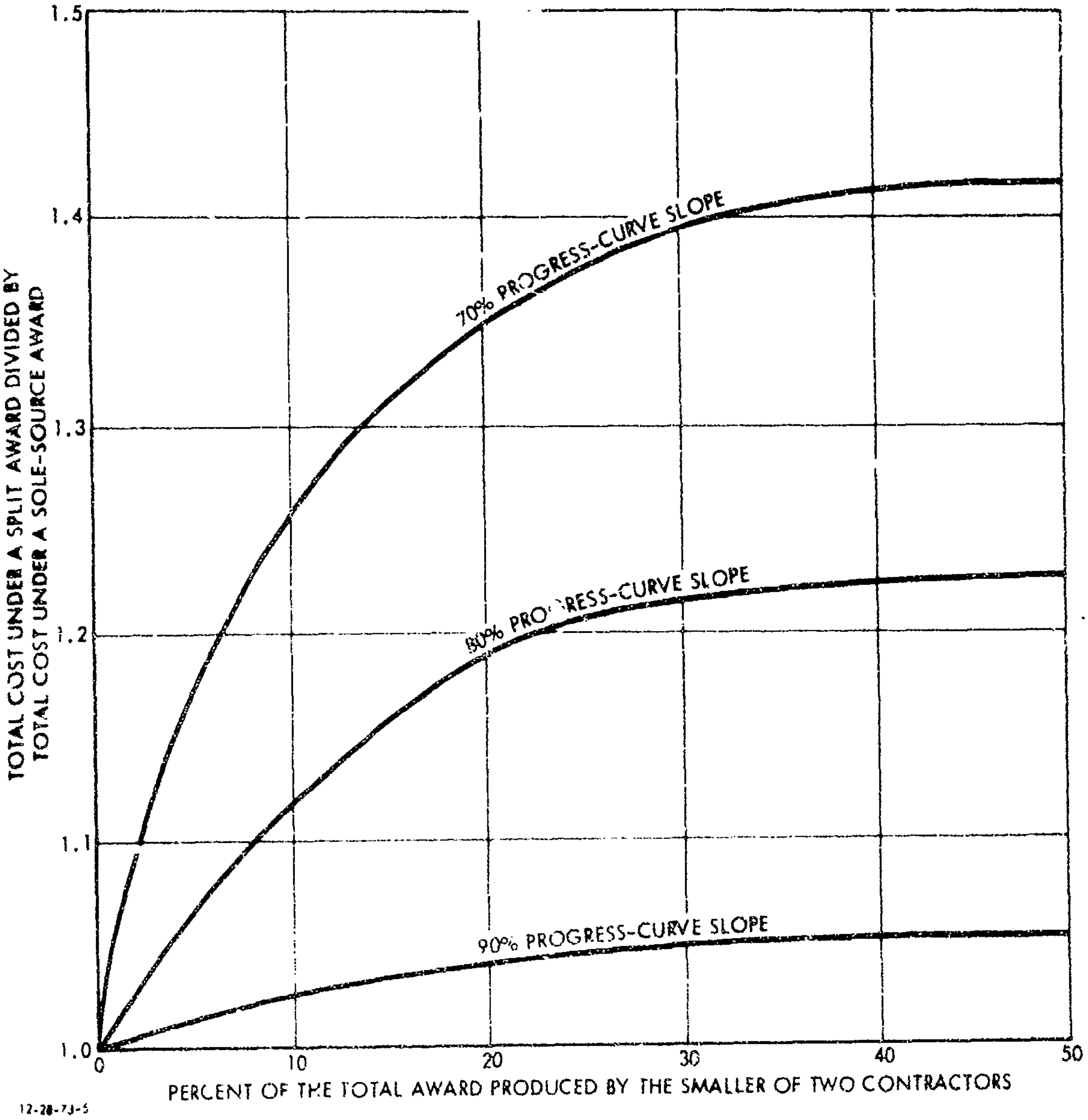

Figure 16. ADDITIONAL COST OF SPLITTING PRODUCTION AWARD DUE TO PROGRESS-CURVE EFFECTS

Chapter V

PRICES OF MILITARY SYSTEMS COMPARED WITH THOSE OF SIMILAR COMMERCIAL SYSTEMS

A. INTRODUCTION

There is a commonly expressed belief that military systems cost considerably more than comparable commercial systems. The objectives of this chapter are to test this hypothesis and to quantify the difference in price between similar military and commercial systems.

In making a comparison between prices of military and commercial equipment, we are limited to equipment for which military and commercial analogues exist. Furthermore, since military and commercial equipment are not identical in performance characteristics, the comparison has to be limited further to equipment that can be normalized to a common basis. For noncombatant aircraft, ships, and wheeled vehicles of similar types, prices can be normalized on a basis of empty weight and/or the weight of useful load carried (payload, crew, supplies, and fuel).

For several important reasons, weight was chosen as the parameter to normalize the end items being compared. First, it is an unambiguous measure. Second, empty weight is highly correlated with the amount of material in a vehicle and, hence, for a particular vehicle type, with the amount of work that went into its fabrication. Thus, it was felt that for the

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types of products compared in this study (transport aircraft, noncombatant ships, and wheeled vehicles) weight was a good surrogate for the "value" purchased. That weight and price are highly correlated is borne out by the regression results that will be presented in subsequent paragraphs, where the unit weight explains 94 percent and 93 percent of the variation in unit-price variable for transport aircraft and wheeled vehicles, respectively.

Some readers may feel that, despite the high correlation between price and weight for the products compared, the products should be compared on a performance basis, since weight does not tell the complete story. The problem with comparing products on a performance basis is that performance is multidimensional. In the case of cargo ships and--to a lesser extent--in the case of transport aircraft, there is a single predominant performance parameter, which is the useful load-carrying capacity of the vehicle. Therefore, in the case of cargo ships, we have made the price comparison on a per-pound basis of useful load-carrying capacity. In the case of aircraft, we have made two comparisons: one on a per-pound basis of useful load-carrying capacity, and the other on a per-pound basis of vehicle empty weight. In the case of trucks, there is no one predominant performance characteristic (e.g., two trucks with the same payload rating might operate over a wide range of terrains and have different horsepower, different numbers of drive wheels, different degrees of ruggedness, etc.). To attempt to develop a technique that could normalize for all the dimensions of performance with the available data would be impossible, and an attempt to account for only some of the performance measures would be subjective and not likely to result in price-predictive equations with properties superior to the regression equations that were derived by use of vehicle weight. Of course, in the case of trucks, comparing military and commercial prices on a weight basis begs the question of whether (for a given payload) military vehicles weigh more than commercial vehicles. Heavier vehicles for a given payload may be correlated with the ruggedness of the vehicles. If the military are requiring their vehicles to meet a harsher environment, then the higher military weight and correspondingly higher price are probably due more to performance specifications than to other procurement practices.

Complicating the comparisons is our inability to obtain commercial cost data, as well as the different relationships between cost and price that generally occur in the civilian and defense marketplaces. In most major military procurements (and aircraft in particular), there is generally a direct correlation between marginal cost and marginal price, while with commercial procurement practices *in those industries that manufacture vehicles* the prices tend to be fixed over large production quantities, even though the marginal production costs may be falling. For example, the cumulative average price per pound (in constant dollars) of delivered C-141s was $101 after the first 21 and $58 after the first 248, over a seven-year period. On the other hand, the cumulative average price per pound paid for delivered DC-8s was $58 for the first 21 and $61 for the first 556, over a 13-year period. The relationship between cost and price for military aircraft programs is conceptually illustrated by Figure 17. In commercial programs, the selling price is approximately constant (in real terms) over an extended period of the program. Initially, the company loses money while the selling price does not cover costs; and later the company makes money when the selling price is greater than costs. Should the company's profits become excessive, other firms would be attracted to the market and the prices would eventually be lowered, in order to maintain the company's competitive advantage. In the case of a military program, the government usually buys in yearly increments and pays a price that covers costs and provides a profit to the company. Because of these differences in pricing practices, it is necessary to compare the revenues

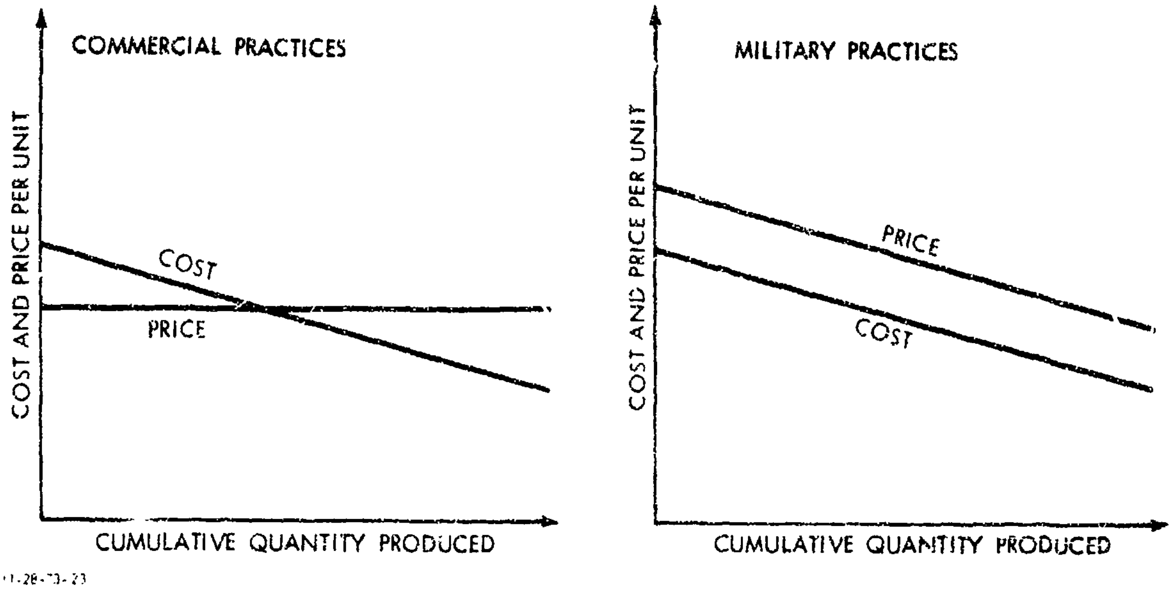

Figure 17. RELATIVE COSTS AND PRICES FOR COMMERCIAL AND MILITARY VEHICLE-MANUFACTURING PROGRAMS

that a commercial producer received for a given product that has earned a profit and the revenues that a military supplier received for an analogous product--both normalized on a weight basis.

B. COMPARISON OF MILITARY AND COMMERCIAL AIRCRAFT

Military combat aircraft generally have characteristics not found in commercial aircraft, and it would be difficult to compare them with any similar commercial systems. However, we believe that large military transports are quite similar to commercial airliners, and we will compare prices for these two types of aircraft. In order to compare prices, it will be necessary to normalize for weight, quantity produced, calendar time, and the amount of government capital provided to the aircraft industry for military aircraft production.

Table J-1 (see Appendix J) presents the airframe cost index used to normalize prices to 1970 dollars.

As part of one of the defense profitability studies cited in Appendix I, the General Accounting Office (GAO) *Defense Industry Profit Study, 1971* [28] presents comparative financial data on commercial and DoD sales for 12 aircraft, missile, and space contractors. This report shows the following profit figures for DoD and commercial sales by these companies:

Profit as Percent of--	Commercial	DoD
Sales	6.6	4.3
Total Contractor Capital Investment	10.0	12.9

As explained in the following text, Table 12 can be constructed with these data, assuming an equal sales price of $100 to both DoD and commercial buyers.

Table 12. COMPARATIVE FINANCIAL DATA FOR $100 IN SALES, COMMERCIAL AND DoD BUYERS

Item	Commercial	DoD
Contractor Cost	$ 93.40	$ 95.70
Profit	6.60	4.30
Selling Price	$100.00	$100.00
Total Contractor Capital Investment	66.00	33.30
Total Government Capital Investment	0	32.70
Charge for Government Capital Investment	0	4.60

Note that for equal selling price the commercial profit is $6.60, while the DoD profit is $4.30. The amount of total contractor capital investment can be calculated from the profit figures as follows:

For commercial: $6.60/.100 = $66.00
For DoD: $4.30/.129 = $33.30

In the case of commercial business, there is no government capital investment; but in the case of DoD business, there is government capital supplied in the form of progress payments, cost reimbursement, equipment, and facilities.

If we assume that the same total capital investment is required for an equal amount of military or commercial sales, then the government capital investment must be approximately $32.70, as shown in Table 12. The total contractor capital investment increases the selling price in two ways: the physical part of the investment (plant and facilities) increases contractor cost through depreciation, and all the investment (physical plus working capital) increases profit, since a return must be earned on this investment. The $32.70 of government capital investment (see Table 12) should also increase price in these same two ways. In order to calculate depreciation on government capital investment, one would have to know the portion represented by plant and facilities and the depreciation schedules for the various plant and facilities items. This information is not available to us. In order to make a calculation, let us assume that half the $32.70 represents plant and facilities and that the average rate of depreciation is 8 percent per year. Depreciation cost would then be 0.5 x $32.70 x 0.08 = $1.31. If we charge a return on investment for the government capital investment equal to that realized on the contractor investment in commercial sales (10.0 percent), then the return on investment for the government capital investment is $3.30. Hence, the cost to the government must be increased by $1.31 + $3.30, or 4.6 percent, to account for depreciation and return on investment of government-provided capital.

Although commercial programs differ in profitability (and some have been unprofitable), the aggregate of commercial programs shows a profit in percent of sales comparable to that of DoD work, according to the figures presented earlier. In the case of commercial sales, RDT&E costs must be recovered in the selling price of the aircraft to the airlines over the life of the program. In the case of military programs, the RDT&E costs are paid for by the government as they are incurred. Hence, a typical military program will have much higher costs to the buyer (DoD) in the early years than is the case in commercial programs. However, by taking the total sales over the life of these programs, we should capture the RDT&E costs as well as the production costs for both. In that way we will be able to compare total program costs for military and commercial programs.

Where RDT&E costs of military aircraft programs were unobtainable, we have estimated RDT&E. This estimate is 50 times the cumulative average cost of the first 100 planes. This estimate was derived from a sample of 12 transport and combat aircraft programs for which actual RDT&E figures, production quantities, and costs were available. To obtain a total program cost, we have used "flyaway costs" as procurement costs and added this RDT&E estimate. Unless otherwise noted, all prices are in 1970 dollars.

Another difference in the cost of military relative to commercial procurement may lie in the in-house procurement cost of the buyer. There is some evidence that the number of government employees (both civil service and military) involved in DoD procurement is considerably greater than the number of, say, airline employees involved in procurement for programs of similar size. We have not been able to quantify this difference and have not included any such differences in our method of analysis.

Two types of comparison were made of military and commercial aircraft prices: (1) on a case-by-case basis, in which individual pairs of military and commercial aircraft were compared; and (2) on an aggregated basis, in which the aircraft prices and weights (empty and useful load-carrying capacity[1]) were correlated and a statistical test was made to determine if there were significant differences between the commercial and military prices.

1. Individual Comparisons

The following is a single case to illustrate the case-study methodology. Note that comparisons are made on bases of aircraft empty weight and aircraft useful load-carrying capacity.

a. Case Study: C-141 Versus DC-8

The DC-8 was developed by Douglas and powered by four Pratt and Whitney jet engines. The C-141 was produced by Lockheed and was powered by the same basic engine as the DC-8. Both were four-engined subsonic transports of approximately the same empty weight.

Table 13 presents data for the DC-8. Note that the total program consisted of 556 aircraft delivered over the 14-year period 1959-72. Sales prices are shown in both current dollars and in 1970 dollars. Total empty weight delivered was 75,310,000 pounds (the total useful load-carrying capacity of the airplanes was 96,742,000 pounds), and total receipts from flyaway sales prices to the airlines were $4.6 billion in 1970 dollars--for a price per pound to the airlines of $61.08 on an empty-weight basis (and $38.79 per pound on a basis of useful load-carrying capacity).

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[1] Useful load-carrying capacity is calculated as the difference between aircraft maximum takeoff weight and aircraft empty weight. As such, it includes the payload, fuel, crew, and any specialized payload-handling equipment that is peculiar to the payload and not the aircraft. Because payload and range are so interrelated, it is not practical to specify payload by itself.

Table 13. DC-8 PROGRAM DATA

Year	Model[a]	Average Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity[b] Delivered thousand pounds)	Average Price (million current $)	Average Price (million 1970 $)	Total Price (million 1970 $)
1959	DC-8-10 DC-8-20 DC-8-30 DC-8-40 DC-8-50	127	21	2,670	3,475	5.6	7.38	155
1960	"	127	91	11,560	15,060	5.8	7.45	678
1961	"	127	42	5,330	6,950	5.9	7.49	315
1962	"	127	22	2,790	3,640	6.0	7.62	168
1963	"	127	19	2,410	3,145	6.1	7.75	147
1964	"	127	20	2,540	3,418	6.5	8.15	163
1965	" plus DC-8-61 DC-8-62 DC-8-63	130	31	4,030	5,300	7.3	8.94	277
1966	"	132	16	2,110	2,840	7.6	8.89	142
1967	"	135	41	5,540	7,218	8.0	9.06	371
1968	"	140	102	14,280	18,106	8.1	8.88	906
1969	"	146	85	12,410	15,090	8.2	8.54	726
1970	"	146	33	4,820	6,220	8.4	8.40	277
1971	"	146	13	1,900	2,450	8.6	8.36	109
1972	"	146	20	2,920	3,770	8.8	8.26	165
Total			556	75,310	96,742			4,599

[a] Years 1959-64 include five DC-8 models; subsequent years include eight models.

[b] Defined as maximum takeoff weight minus empty weight.

Table 14 presents C-141A program cost data. The current-year dollar figures have been converted to 1970 dollars by the cost index of Table J-1 (see Appendix J). Note that total RDT&E cost was approximately $203 million. A total of 284 airplanes was built; the unit flyaway costs for each year's buy are shown in Table 14. Flyaway costs were converted to a cumulative average basis and plotted in Figure 18. A trend line was fitted through the points. To normalize the C-141A program prices with the DC-8 program for number of aircraft built, it is estimated from Figure 18 that the C-141A cumulative average cost would have been $6.8 million if production had been continued to a total of 556 aircraft.

Table 14. C-141A PROGRAM COSTS

Year	RDT&E (million 1970 $)	Quantity	Unit Flyaway Cost (million 1970 $)
1961	0.13	5	17.70
1962	88.27		
1963	83.95	16	12.38
1964	12.41	45	7.46
1965	12.25	84	9.46
1966	5.03	100	5.85
1967	--	34	6.33
1968	1.21	--	--
Total	203.25	284	

In Table 14, it was assumed that the 1961 and 1962 RDT&E funds were used to produce the five aircraft paid for with RDT&E funding. Hence, the RDT&E funding not reflected in aircraft flyaway costs was the total RDT&E funding for 1963

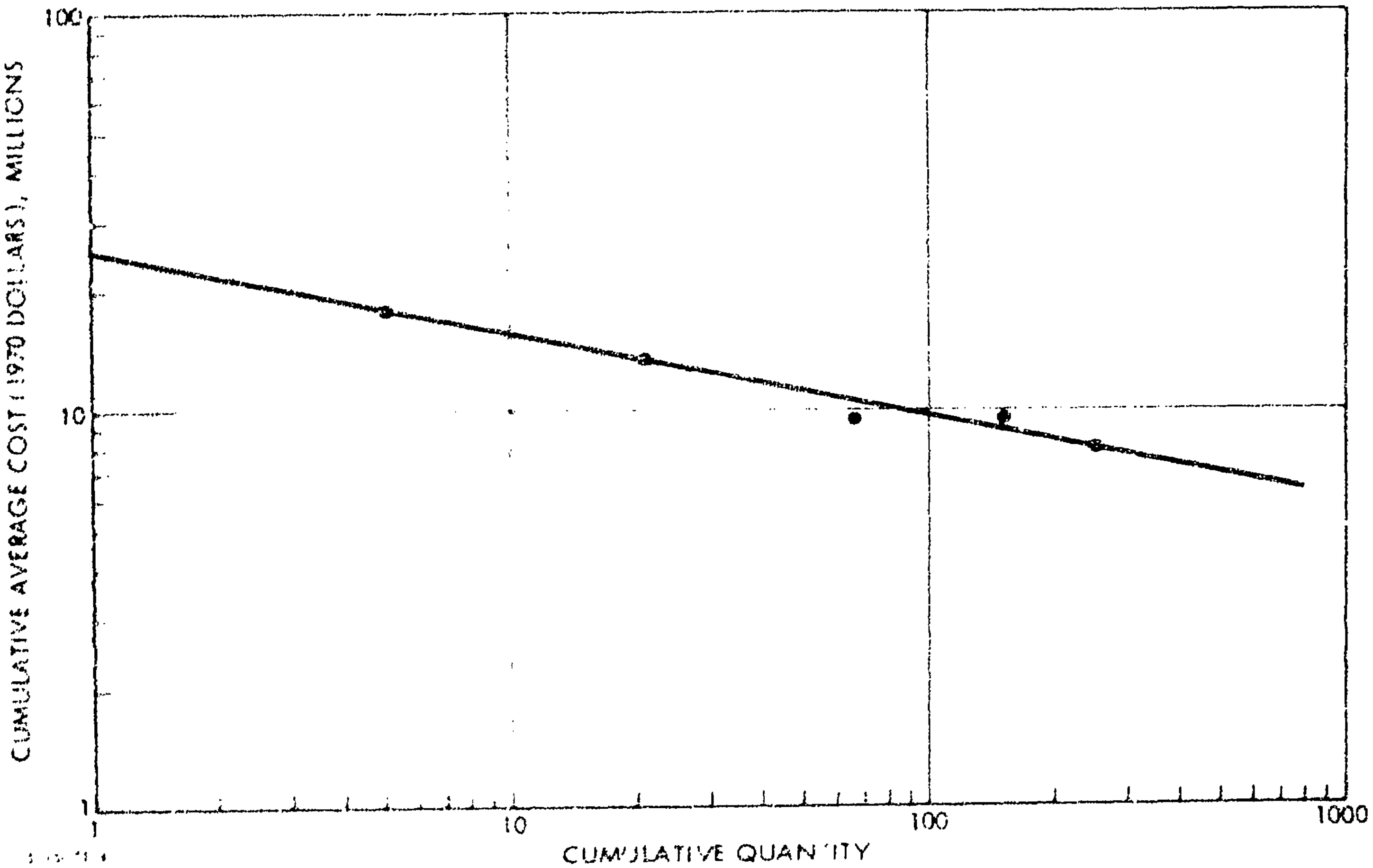

Figure 18. C-141A COST-QUANTITY RELATIONSHIP

through 1968, or $114.85 million. C-141A total cost in millions of 1970 dollars for a program of 556 aircraft would have been as follows:

RDT&E	$ 115
Aircraft Flyaway (556 x 6.8)	3,781
	$3,896

To account for government-provided capital, the price paid to Lockheed should be increased by 4.6 percent--for a resulting $4,075 million.

The empty weight of the C-141A was 134,203 pounds with a useful load-carrying capacity of 188,890 pounds. Hence, total empty weight for 556 aircraft would have been 74,616,868 pounds, and the average price per pound of empty weight would have been $54.61. Likewise, the total useful load-carrying capacity for 556 C-141s would have been 105,026,000 pounds, and the average price per pound of useful load-carrying capacity would have been $38.79.

The ratio of price per pound for the C-141A versus the DC-8 was $54.61/$61.08 = 0.89. Similarly, the ratio of price per pound of useful load-carrying capacity for the C-141A versus the DC-8 was $38.79/$47.53 = 0.82. The higher price per pound for the DC-8 was probably due to the fact that there were eight models and many airline customers. The stretched DC-8-60 series, in particular, was quite different from the earlier DC-8 models. On the other hand, only one model of the C-141 was built; and all were delivered to a single customer, the U.S. Air Force. Nevertheless, the analysis above indicates that in the C-141A program the Air Force obtained airplanes at a price competitive with prices of comparable aircraft in the commercial world.

b. Other Aircraft Comparisons

Table 15 presents the results for all the aircraft-pair comparisons. The method for making the pair comparisons

Table 15. MILITARY-COMMERCIAL AIRCRAFT PRICE COMPARISON

Military Aircraft	Commercial Aircraft	Number of Commercial Aircraft Produced[a]	Military Price[b]/ Commercial Price (empty-weight basis)	Military Price[b]/ Commercial Price (useful-load basis)[c]
Piston	Convair 240, 340, 440[d]	563		
C-119	Constellation	519	0.90	0.96
C-123	DC-6	537	1.08	0.94
C-124	DC-7	336	0.89	0.59
Turboprop				
C-130	Lockheed Electra[e]	164	1.16	1.08
Pure jet				
KC/C-135	Boeing 707	704	0.80	0.67
C-141	DC-8	556	0.89	0.82
C-5A	Boeing 747	556 (projected)	1.27	0.94
Average			0.99	0.86
B-52	Boeing 707	704	1.05	0.85

[a] Military Aircraft costs were normalized to this quantity to make the comparison.

[b] On a dollars-per-pound basis.

[c] Useful load is defined as the maximum takeoff weight minus empty weight.

[d] Each military aircraft was individually compared with each series of commercial aircraft. The military price/commercial price presented is the average of each of the four comparisons.

[e] The Lockheed reported loss of $120.7 million (converted to 1970 dollars) was added to the Electra price for this comparison.

was similar to the comparison of the C-141A and the DC-8. (The detailed analyses may be found in Appendix J.)

Table 15 shows the comparisons made on bases of both dollars per pound of empty weight and dollars per pound of useful load-carrying capacity between the other[1] pairs of commercial and military aircraft normalized using progress curves to the number of commercial aircraft actually built. In the case of the 747, which is still being built, we extrapolated to a quantity of 556, which was the number of DC-8s built. The pairs are all of essentially the same technology, and they are grouped by engine type. Normalized price ratios on a basis of dollars per pound (both empty weight and useful load-carrying capacity) were developed. The ratios are the military price divided by the commercial price. If the ratio is more than 1.00, then the military airplane on a per-pound basis cost more than the commercial plane; if it was less than 1.00, then the commercial price was higher.

The C-119 was individually compared with the Convair series, Constellation series, DC-6, and DC-7; and the four derived price ratios were arithmetically averaged. This average indicated that the C-119 cost 10 percent less than these civilian aircraft. Similar comparisons were made for the C-123 and C-124. In the case of the Electra, where Lockheed lost $127 million, this amount was added to the Lockheed cost.

As can be seen from Table 15, the average of the eight pair comparisons is 0.99 on an empty-weight basis and 0.85 on a basis of useful load-carrying capacity. One reason that commercial aircraft seem to carry less useful load for a given empty weight than military aircraft do involves the financial exposure of the manufacturer to claims arising from commercial

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[1] The method for making the other pair comparisons was similar to that for making the comparison between the C-141 and the DC-8 (the detailed analyses may be found in Appendix J).

aircraft operations. The commercial aircraft fly many more hours over their lives, and the manufacturers are required to give warranties to the airlines. For example, Boeing warrants the 747 for 10 years or 30,000 flight-hours. In order to assure the necessarily greater fatigue life for a commercial transport, as well as to provide protection against commercial warranty claims, most manufacturers design more strength into their commercial aircraft; hence, for equal empty weight, the aircraft carry less useful load (or for equal gross weight, the empty weight of the commercial aircraft may be greater). Admittedly, the method we used to make the comparisons was quite rough; but if military costs were much greater than civilian costs, even a rough measuring technique would detect them. The results certainly indicated that if differences do exist they are not large. However, this is not to say that the military can be satisfied with the costs. There are a number of factors (such as number of customers, which results in numerous different configurations and model changes; better commercial warranties; etc.) that would tend to inflate the civilian costs that the military does not have to contend with.

The B-52/Boeing 707 comparison (shown in Table 15 but not included in the averages) was undertaken after it appeared that there was no difference in normalized price between military cargo and commercial transports. The Boeing B-52 was the obvious choice of a combat aircraft for the comparison because of its data availability and its comparability (with the Boeing 707) of cruising speed, cruising altitude, period of production, and number produced. A normalized price per pound of $65.08 was calculated for the first 704 of a total of 742 B-52s ultimately produced. This compares to a normalized price per pound of $62.26 for the first 704 Boeing 707s produced, which results in a military price/commercial price ratio of 1.05. The closeness of the 707 and B-52 prices is even more striking in light of the fact that the B-52 has much more avionics equipment than the 707. The B-52 avionics equipment not found on the 707 includes more communication equipment, bomb navigation equipment, and ECM equipment--all o which are included in the B-52 flyaway price and have high price-to-weight ratios. Further, the B-52 (unlike some of the other military aircraft) went through extensive model changes, in addition to having the production plant shifted from Seattle to Wichita during the production run.

2. Aggregated Comparisons

a. Aircraft Empty-Weight Basis

A statistical comparison of commercial and military aircraft prices was made, using a broader spectrum of aircraft than was used in the specific aircraft-pair comparisons. Figure 19 presents a plot of the average price (adjusted to 1970 dollars) versus the average empty weight of the aircraft for the 30 aircraft used in the comparison. All the average prices of the aircraft shown in Figure 19 are based on the actual number of military aircraft built; they include the RDT&E cost and have escalated 4.6 percent to adjust for government-furnished capital. The average price shown for the Electra and Convair 880-990 aircraft include the losses reported for these aircraft by Lockheed and General Dynamics, respectively.

A regression equation (12a), which explained 94 percent of the variance in the average price, was fitted to the data and is represented by the solid lines in Figure 19:

$$C = 0.060 \times 0.442^{P} \times W^{1.0384} , \qquad (12a)$$

where

C = cumulative average cost (in millions of 1970 dollars);

P = a dummy variable (if the aircraft is piston, P = 1; otherwise, P = 0); and

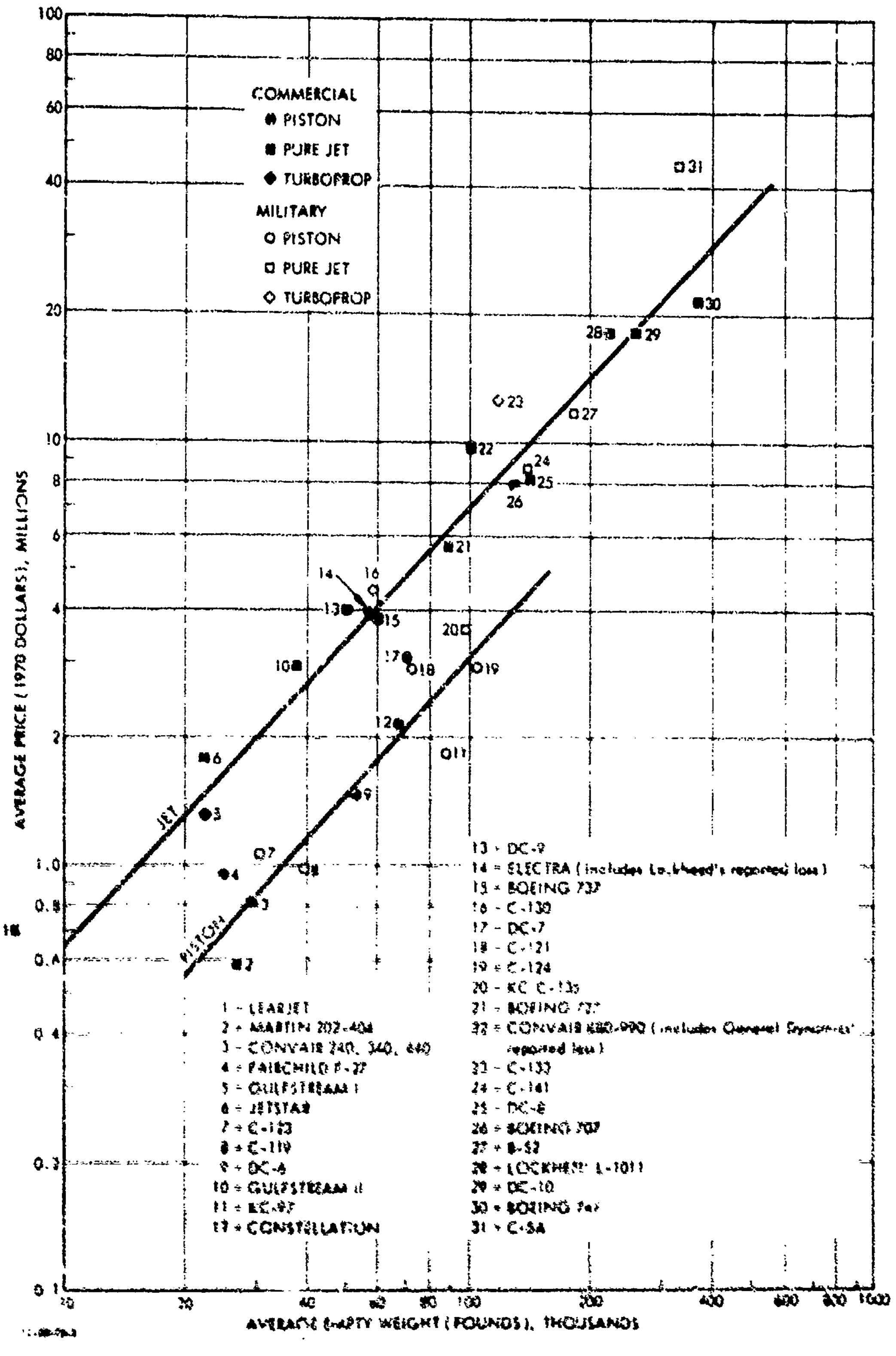

Figure 19. TRANSPORT AIRCRAFT AVERAGE PRICE VERSUS AVERAGE EMPTY WEIGHT

W = aircraft empty weight (in thousands of pounds).

All coefficients of the equation are significant at the .01 level. While there was a significant difference in prices between piston and jet aircraft, no significant differences could be found between military and commercial aircraft prices. This is visually displayed in Figure 19, where it can be seen that there is a strong correlation between empty weight and price for both military and commercial aircraft.

It is interesting to note that the three aircraft that fall farthest from the regression line (the C-5A, C-133, and KC/C-135; the first two on the high side and the last on the low side) lie at the two extremes for production quantities. Only 81 C-5As and 50 C-133s were built, while 777 KC/C-135s were built. These empirical data are consistent with the military pricing practice shown in Figure 10, which indicates that military prices drop as the cumulative quantity of aircraft increases. A second regression, Equation (12b), was derived that used as explanatory variables both the average weight and the quantity of military aircraft built. This second regression equation (12b), which explained 95 percent of the average price variation, indicated that there were significant differences between military and commercial price and that the quantity of military aircraft produced was significant:

$$C = 0.062 \times 3.34M \times 0.454^{P} \times W^{1.035} \times N^{-0.2216M} , \qquad (12b)$$

where

M = a dummy variable (if the aircraft is military, $M = 1$; otherwise, $M = 0$); and

N = the cumulative number of aircraft produced.

All coefficients are significant at the .01 level.

The solution of the second regression equation (12b) indicated that military and commercial prices could be expected to be equal when 230 military aircraft were produced. If less than 230 military aircraft were produced, commercial prices would be expected to be less than military prices; and if more than 230 military aircraft were produced, commercial prices would be expected to be more. For example, Equation (12b) predicts that the ratio of average military price to average commercial price for a given weight and type of aircraft would be 1.10 when 150 military planes had been built and 0.90 when 380 military planes had been produced.

b. Aircraft Useful-Load-Carrying-Capacity Basis

The analysis was extended by comparing military and commercial aircraft prices on a basis of useful load-carrying capacity rather than empty weight. Figure 20 presents the average aircraft prices plotted against the average useful load-carrying capacity of the aircraft.

A regression equation (13), which explained 93 percent of the variance in the average price, was fitted to the data and is represented by the lines in Figure 20:

$$C = 0.113 \times 0.551^{P} \times 0.747^{M} \times UW^{0.903} , \qquad (13)$$

where

C = cumulative average cost (in millions of 1970 dollars);

P = a dummy variable (if the aircraft is piston, $P = 1$; otherwise, $P = 0$);

M = a dummy variable (if the aircraft is military, $M = 1$; otherwise, $M = 0$); and

UW = the useful load-carrying capacity of the aircraft (in thousands of pounds).

All coefficients of the equation are significant at the .025 level. As can be seen from the regression equation, a "significant" difference was found between the prices of military and commercial aircraft when compared on a basis of useful load-carrying capacity. The regression equation states

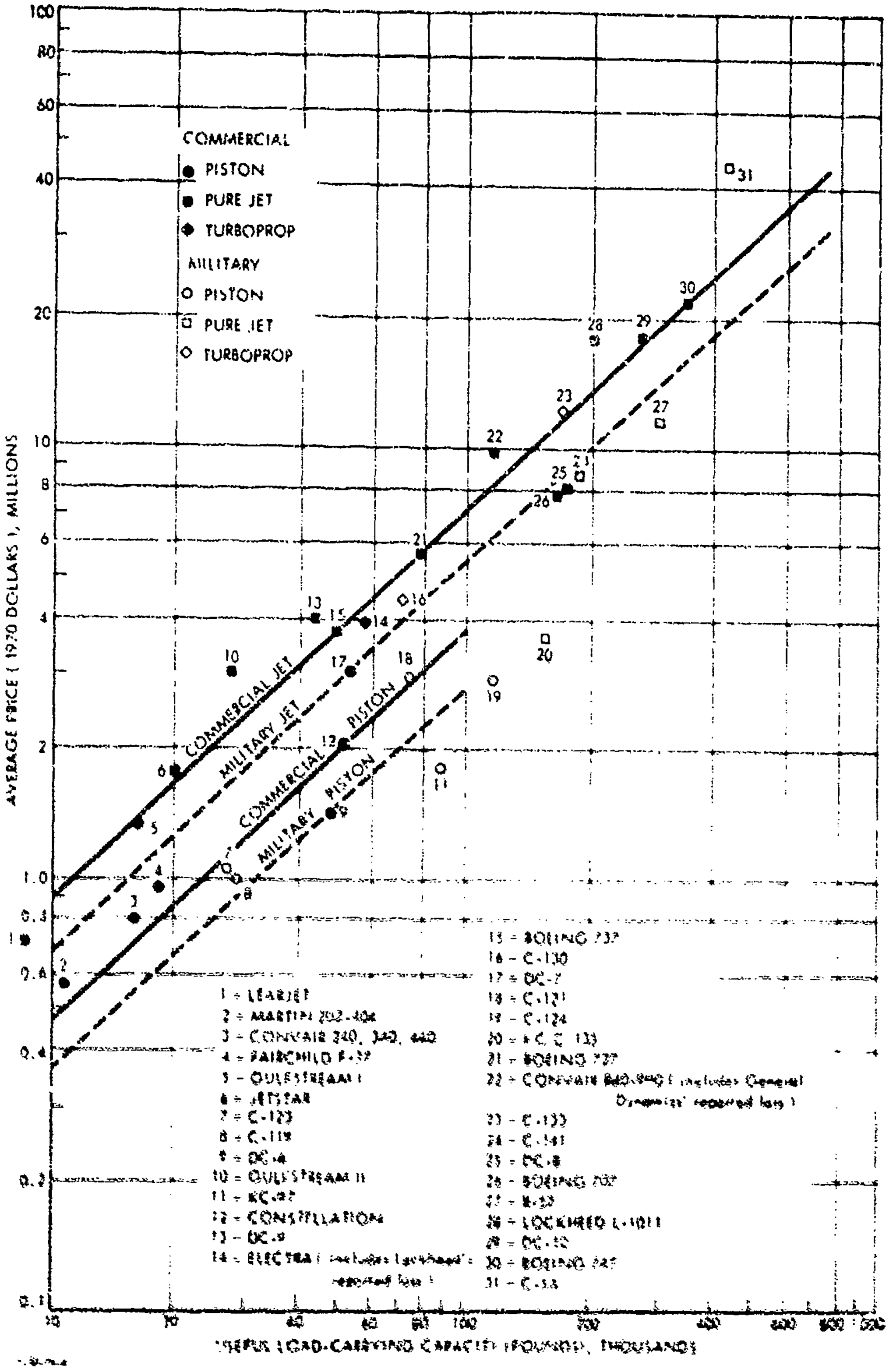

Figure 20. TRANSPORT AIRCRAFT AVERAGE PRICE VERSUS USEFUL LOAD-CARRYING CAPACITY

that the most likely relationship between military and commercial prices is that, on average, military prices will be 20 percent lower than commercial prices. For a 95-percent confidence band, the true amount that military prices are lower than commercial prices could range between 8 and 40 percent.

In addition to the regression equation (13) depicted in Figure 20, another regression equation was derived that had as an explanatory variable (additional to the explanatory variables incorporated in Equation 13) the number of military aircraft produced. This regression equation, which explained 95 percent of the variance in the average aircraft price variable and had all coefficients significant at the .01 level, is given by

$$C = 0.113 \times 0.591^{P} \times 3.287^{M} \times UW^{0.897} \times N^{-0.258M} , \qquad (14)$$

where N = the cumulative number of aircraft produced, and other variables are as defined for Equation (13).

The solution of the regression equation (14) indicated that military and commercial prices could be expected to be equal when 100 military aircraft were produced. On a basis of useful load-carrying capacity, if less than 100 military aircraft were produced, commercial prices would be expected to be less than military prices; if more than 100 military aircraft were produced, commercial prices would be expected to be more.

3. Summary

This analysis does not support the hypothesis that military aircraft prices are higher than similar commercial aircraft prices. This is not to say the military should be satisfied with its aircraft prices. There are some factors that would tend to increase commercial costs relative to military costs. Among them are the greater number of customers for commercial aircraft, resulting in more configuration changes, more stringent commercial warranties, greater commercial risk, etc. Accordingly, it is possible that military aircraft should cost somewhat less than similar commercial aircraft.

C. COMPARISON OF MILITARY AND COMMERCIAL SHIPS

Navy combatant ships have many features and much equipment not found in commercial ships, and any valid comparison of construction costs of Navy and commercial ships would be most difficult. Case studies for both the tankers and the roll-on/roll-off (RO/RO) ships are presented below. They were compared on a basis of unit price versus useful load-carrying capacity.[1]

Figure 21 presents a plot of contract price versus deadweight tons (DWT) for nine different types of commercial and Military Sealift Command (MSC) tankers in the size category of 25,000-120,000 DWT currently under construction in U.S. shipyards. As can be seen from the plot, the price of the military tanker lies within the normal commercial price trend for tankers from 25,000 to 120,000 DWT.

We performed a similar analysis for U.S.-built commercial and military RO/RO ships by plotting prices versus weight. Figure 22 indicates that prices of military RO/RO ships lie within the normal range of commercial RO/RO ship prices.

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[1] For tankers, the measure of useful load-carrying capacity used was deadweight tons (DWT), defined as the total weight of liquid and/or dry cargo, equipment, fuels, crew equipment and provisions, and potable water. For RO/RO ships, the measure of useful load-carrying capacity used was gross tons (approximately, the total internal capacity in cubic feet divided by 100), which indicate the revenue-earning capacity of the ships. Two similar but different measures of useful load-carrying capacity were used because of the form in which the available data were found. (Source of the definition. U.S. Maritime Administration, *Design Characteristics* [29].)

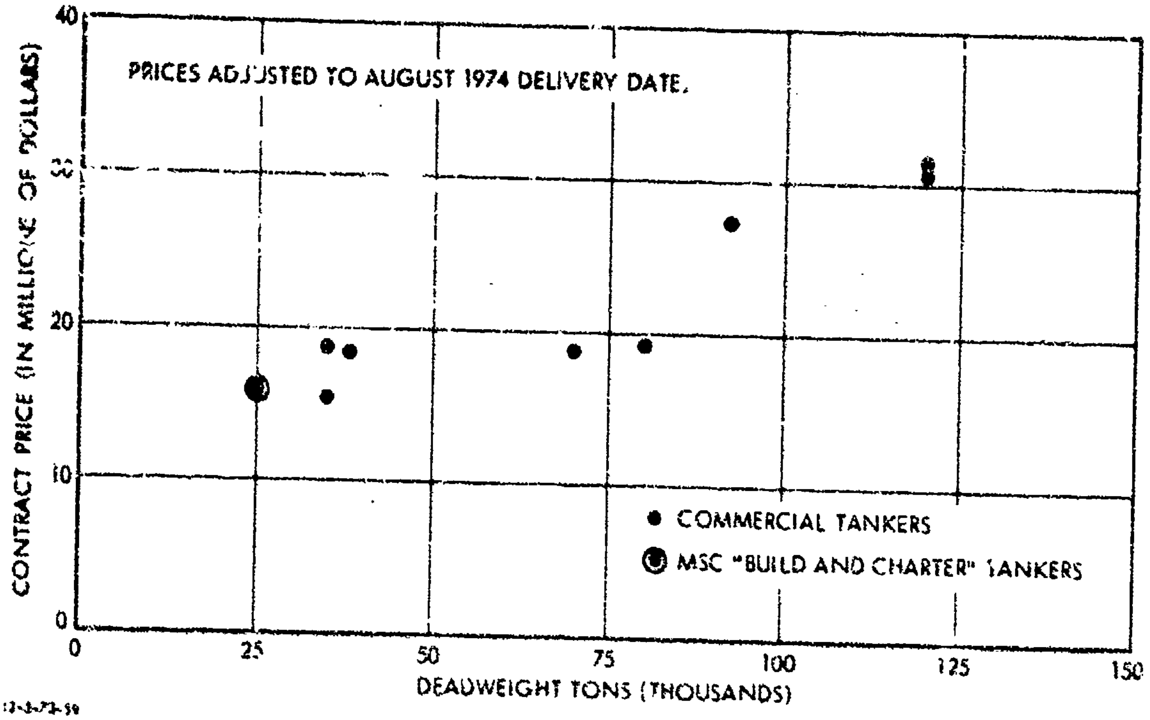

Figure 21. U.S.-BUILT TANKER PRICES

D. COMPARISON OF MILITARY AND COMMERCIAL WHEELED VEHICLES

In making a comparison of military and commercial wheeled vehicles, we are again forced to eliminate all the combat vehicles, since there are no civilian counterparts. Therefore, we compared a broad range of general-purpose military and commercial trucks. All the military vehicles were vehicles built to military specifications and not merely commercial off-the-shelf vehicles with paint of another color. Figure 23 shows a plot of the cost versus the curb weight of the vehicle. Curb weight is defined as the weight of the vehicle including fuel, lubricants, coolant, and on-vehicle material but excluding payload and operating personnel. A regression analysis was run on the data to see whether significant differences could be detected between the military and commercial vehicles. The lines in Figure 23 present the solution of Equation (13), which was derived by the regression analysis.

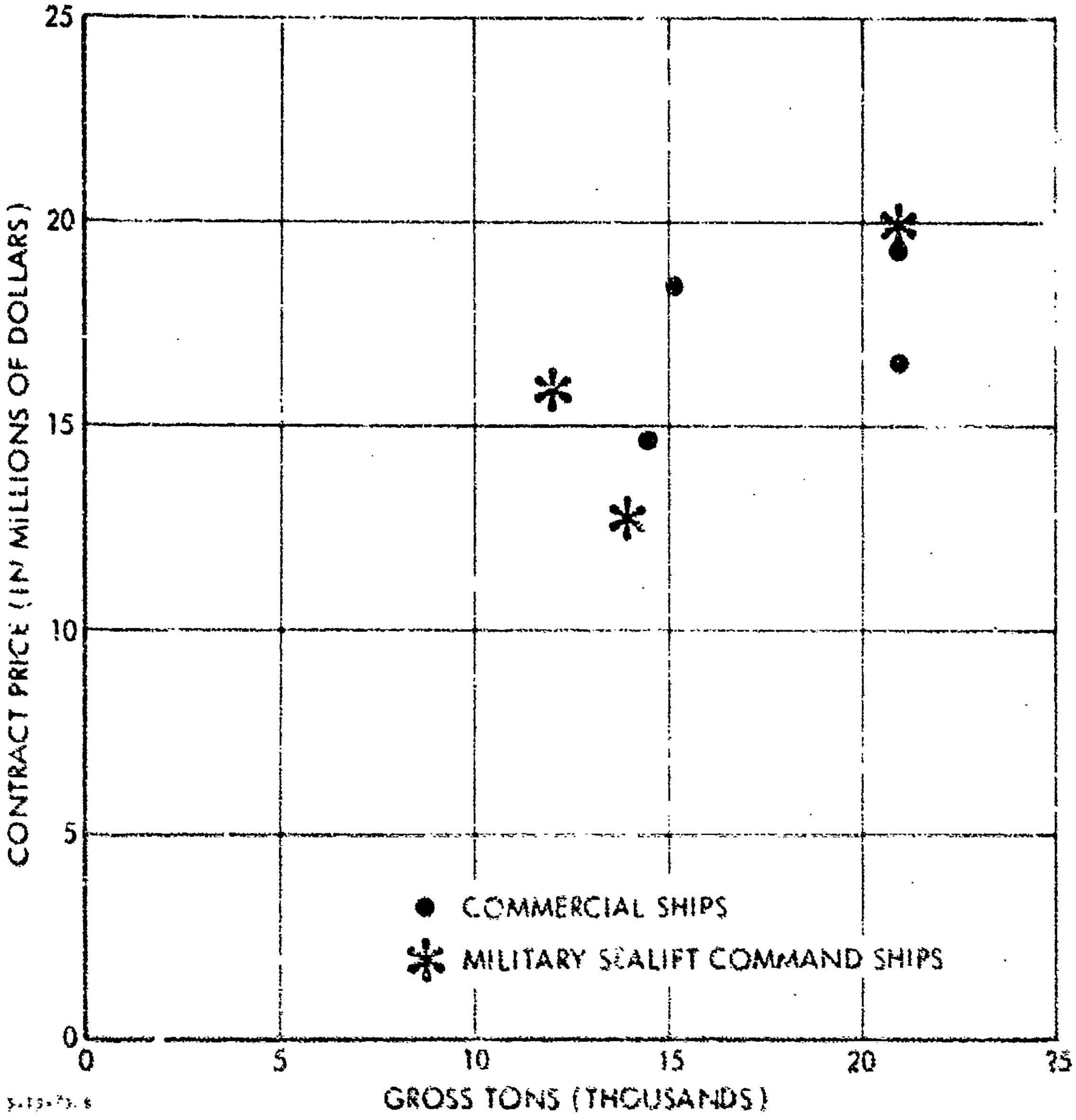

Figure 22. U.S.-BUILT ROLL-ON/ROLL-OFF SHIP PRICES

Equation (13) is the result of the regression analysis:

$$C = 0.134 \times 0.766^{M} \times W^{1.257} , \qquad (13)$$

where

C = the vehicle cost (in dollars);

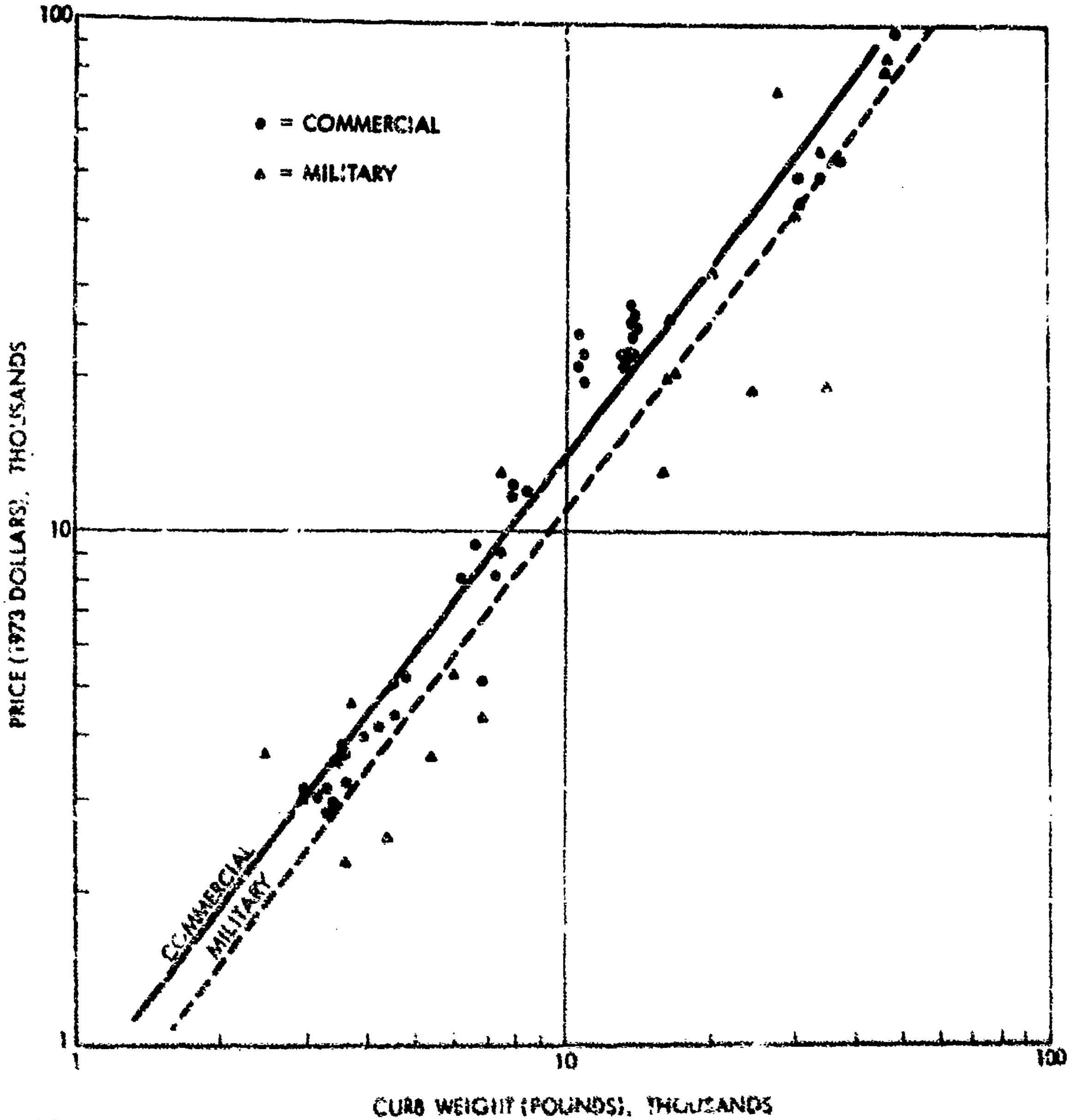

Figure 23. MILITARY AND COMMERCIAL WHEELED VEHICLES, PRICES VERSUS WEIGHT

M = a dummy variable (it is 1 for military vehicles, 0 for civilian vehicles); and

W = the weight of the vehicle (in pounds).

All coefficients are significant at the .01 level.

Note that a significant difference was found between military and commercial vehicles. On average for a given weight vehicle, the military prices were 24 percent lower than the commercial prices. These data are consistent with data obtained in a 1970 U.S. Army study [30] that is presented in Table 16. Of special interest is the fact that tracked vehicles were included in the Army cost comparison and that, on a per-pound basis, the standard military average list prices are 23 percent lower than prices paid for standard commercial vehicles. Note that Table 16 shows that the price of air mobile equipment is significantly more expensive than both commercial equipment and standard military equipment. This result is not too surprising, since extra expenses are included in making air mobile vehicles lighter than standard vehicles. These extra costs, together with the lighter weight, not surprisingly result in significantly higher dollars-per-pound figures for air mobile vehicles.

Again, there are some reasons why the commercial prices seem higher. The commercial prices are the manufacturer's suggested prices, while the military prices are those actually paid by the military. There are undoubtedly discounts[1] that would tend to reduce or eliminate the 23-24 percent price difference found. However, it would certainly appear that standard military vehicles on a per-pound basis are not significantly more expensive than commercial vehicles.

As was mentioned earlier, the analysis excludes the question: For a given performance or payload, do the military and

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[1] The *Wheels* study [31]--Office, Chief of Staff, U.S. Army, *Special Analysis of Wheeled Vehicles (Wheels), Phase II Report*--estimated that the Army when buying commercial trucks would receive a 25-percent discount from the manufacturer's list price (Annex E to Part 2 of Vol. II, August 1972). Telephone conversation with a representative of Ford Motor Company [32] indicated that Ford sells trucks to the Federal Government at a price that is $200-$500 per truck less than Ford charges its dealers. Dealer markup is approximately 20 percent.

Table 16. COMPARISON OF STANDARD MILITARY, AIR MOBILE, AND COMMERCIAL VEHICLE PRICES ON A WEIGHT BASIS*

Vehicle	$/Lb Standard Military Procurement	$/Lb Air Mobile Military Procurement	$/Lb Commercial List Price	Ratio: Standard Military/ Commercial	Ratio: Air Mobile Military/ Commercial
Tracked Tractors	0.616	0.355	0.836	0.737	1.023
Wheeled Tractors	0.733	1.430	0.937	0.782	1.526
Graders	0.622	0.667	--		
Loaders	0.693	1.100	1.015	0.683	1.084
Towed Scrapers	0.546	1.030	0.710	0.769	1.451
Motor Scrapers	0.968	1.200	1.020	0.949	1.176
Average	0.696	1.047	0.904	0.784	1.252

Size of Sample

Vehicle	Military Standard	Military Airmobile	Commercial
Tracked Tractors	15	1	41
Wheeled Tractors	6	1	23
Graders	3	1	--
Loaders	3	1	9
Towed Scrapers	4	1	2
Motor Scrapers	1	1	34

*Extract from U.S. Army Mobility Equipment Command Study entitled *Pilot Improved Cost Estimates (ICE) Phase 2 (April 1970), FAMECE (Family of Military Engineer Construction Equipment).*

commercial trucks weigh and cost the same? The *Wheels* study [31], which attempted to identify commercial trucks that could be used as military equivalents, sheds some light on the question. Recognizing that military vehicles are designed for a degree of mobility that would be experienced only in a front-line combat situation (a situation that many vehicles will never experience while doing their assigned missions), the *Wheels* study set out to identify commercial trucks that could be used as substitutes for military trucks that would never be expected to be in front-line combat situations. Paragraph V.3.b.1 of Annex D to Part B of Volume II of the *Phase II Report* (which discusses the rationale for selection of the candidate commercial trucks) is of particular relevance:

> Commercial vehicles selected for substitution into the military vehicle fleet were configured to the same GVW as their military counterparts. Inasmuch as the curb weight (CW) of the commercial vehicle is, in most cases, less than the military version, a greater payload capacity can be credited to the commercial. However, the cargo volume is essentially the same for both and this is considered the limiting factor. The result is that the Study Group selected a rugged truck for the commercial candidate instead of the lightest possible version....

Further, the *Wheels* study identified six payload classes in which commercial trucks might substitute for military trucks on some missions. Table 17 (excerpted, with the exception of the last column, from the *Wheels* study) presents the price data for general-purpose trucks for which commercial substitutes were identified. There are several factors to be considered in studying Table 17. First, the prices presented for the commercial vehicles were discounted (by the *Wheels* study) 25 percent from the manufacturer's list prices to account for the discount that the military might expect. Second, military vehicles have a greater mobility capability (in terms of the terrain they can traverse) than the similar commercial trucks. Third, many of the commercial trucks may have a greater

Table 17. PRICES OF SELECTED GENERAL-PURPOSE MILITARY AND CANDIDATE COMMERCIAL-SUBSTITUTE TRUCKS

Payload Class (tons)	Vehicle Designation	Unit Hardware Price (1972 $)	Curb Weight[a] (pounds)	Average Military Price/ Average Commercial Price
1/4	M151A2, 4x4[b]	3,207	2,700	1.10
	M151A2, 4x2	2,608	2,700	
	M151A2, 4x4 (derated)	2,530	2,700	
	Commercial, 4x2	2,326	3,540	
	Commercial, 4x4	2,726	3,540	
1-1/4	M715, 4x4[b]	4,788	5,900	1.46
	M715, 4x2	4,184	5,900	
	Commercial, 4x2	2,866	4,500	
	Commercial, 4x4	3,266	4,500	
2-1/2	M35A2C, 6x6[b]	10,857	13,800	1.46
	M35A2C, 6x4	9,773	13,800	
	Commercial, 4x2	5,817	9,520	
	Commercial, 4x4	8,318	9,520	
5	M813A1, 6x6[b]	15,379	21,840	1.18
	M813A1, 6x4	13,682	21,840	
	Commercial, 6x4	12,278	7,615	
5[c]	M818, 6x6[b]	14,984	34,930	0.89
	M818, 6x4	13,287	34,930	
	Commercial, 6x4	14,900	17,830	
	Commercial, 6x4	17,000	17,830	
22-1/2[d]	XM746, 8x8[b]	89,339	73,669	1.55
	Commercial, 8x4	55,000	60,738	
	Commercial, 8x8	60,000	60,738	
Average				1.27

[a] Estimated by subtracting the payload from the gross vehicle weight, since only the latter was presented in the source.

[b] Standard military vehicle.

[c] Tractor with 12-ton 4-wheel trailer.

[d] Tractor with 52-1/2-ton trailer.

Source: Office, Chief of Staff, U.S.Army, *Special Analysis of Wheeled Vehicles (Wheels), Phase II Report*, Volume II (August 1972), Part B, Annex E, Enclosures 13-18.

load-carrying capacity than Table 17 indicates, since the requirement for the commercial vehicles to be considered a military substitute was that they carry at least as much as the similar military vehicle. Finally, the commercial vehicles cannot be considered a random sample. Since the object of the *Wheels* study was to identify low-cost alternatives, no commercial vehicle would be considered whose cost exceeded that of the military vehicle for which it was going to substitute. For that reason, the standard military truck is most expensive in every payload class except the 5-ton tractor. The military 5-ton tractor was considered under-powered; and, hence, the commercial tractor selected has significantly more payload capacity than the military tractor.

Because the commercial trucks shown in Table 17 were selected by the *Wheels* study in such a way that the commercial trucks would almost always cost less than the military trucks, the *Wheels* data cannot be used to test the hypothesis that military trucks, on average, cost more than similar commercial trucks of the same payload class. All that the data from the *Wheels* study demonstrate is that there are some specific commercial trucks that are cheaper than specific military trucks of the same payload class--and further, that when commercial substitute trucks are selected with the criterion that they must be cheaper than the military trucks they will substitute for, then they are, on average, 27 percent cheaper than the military trucks.

The quotation from the *Phase II Report* and the subsequent discussion (above) would indicate that, for a given payload, military vehicles are heavier than commercial vehicles and, therefore, (while costing the same or less on a per-pound basis) may cost more on a payload basis. However, it should be pointed out that the weight of the vehicle is correlated with the ruggedness of the vehicle. Thus, the potentially higher military vehicle prices are probably due more to performance requirements than to other procurement practices.

E. COMPARISON OF MILITARY AND COMMERCIAL ELECTRONIC EQUIPMENT

In the case of electronic products, where the packaging makes up a significant amount of the weight (but is relatively cheap, compared to the electronic components), it is believed that weight would not be an appropriate parameter on which to base comparisons. An attempt was made to identify performance-related parameters on which to normalize electronic equipment prices.

An example of the problems encountered in trying to make a comparison between military and commercial prices of electronic equipment is illustrated by two inertial navigators: the LTN-51, used in a number of commercial aircraft; and the ASN-86, designed for military tactical use. Both items are built around the same inertial platform (the LN-15), have very similar computers, and perform with about the same rate of error. However, the more costly ASN-86 was designed to meet more difficult environmental conditions and to have a complex interface with other military equipment. For example, in the military version, the aircraft's position could be automatically updated from the TACAN set. These additional requirements impacted throughout the entire system to the point that the Litton engineers stated that the two equipments were not at all comparable and that to make the LTN-51 meet the requirements set for the ASN-86 would mean the complete redesign of the former and increase its cost to that of the latter. It quickly became apparent that, within the limited resources allocated for this portion of the study, meaningful quantitative comparisons between military and commercial electronic equipment could not be made.

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APPENDIX A

TABLE OF REGRESSION RESULTS FOR AIRFRAMES, SHOWING THE EFFECT OF EXPLANATORY VARIABLES ON UNIT COST

Appendix A

TABLE OF REGRESSION RESULTS FOR AIRFRAMES, SHOWING THE EFFECT OF EXPLANATORY VARIABLES ON UNIT COST

This appendix includes regression results that have cumulative output and additional variables that "explain" variations in cost. These additional variables are lot size, flattening effect, production rate, and model changes. The resultant regression statistics are listed for each aircraft. The regressions were based on data contained in the Cost Information Reports (*Aircraft Learning Curves*) of the Naval Air Systems Command [7]. All variables except model "dummies" were transformed into natural logarithmic form. For the dependent variable, we used each lot's man-hours per pound of airframe.

All coefficients that had absolute t-values greater than 1 were included in Table A, since they improved the coefficient of determination (R^2), corrected for degrees of freedom, even though they might not be statistically significant. While the exact t-value that a coefficient would have to have to be considered statistically significant at the .1 level in a two-sided test depends on the number of degrees of freedom associated with the regression equation, a good rule of thumb is that any coefficient that has an absolute t-value less than 1.8 is probably not statistically significant.

As explained in Chapter III, Section D, the flattening effect for the AD and the A-4 aircraft was obtained by dividing the data for each aircraft into two parts (one representing the steep part--and the other, the flat part--of the progress curve).

The model change variable Di is a "geometrically lagged dummy." It is described in Subsection 1 of Chapter III, Section G.

As can be seen in Table A (and as noted in Chapter III, Section G.1), for the AD and A-4 aircraft, the dummy variables associated with model change are not particularly satisfactory when they are utilized in the flattened segment of the progress curve. We would normally expect an increase in price with the introduction of a model change, with the result that the coefficient associated with the model-change variable should always be positive. However, in the case of both the AD and the A-4, we find a negative coefficient associated with one of the model changes. The reason appears to be that, in the flat range of observed data, the cumulative-quantity and model-change effects are so collinear that the estimated coefficient pertaining to cumulative quantity is also picking up the influence of model change, thus overstating the effect of cumulative quantity or cost. Therefore, for the segment of the progress curve beyond the flattening points, it is not warranted to consider the estimates to be structural estimates; and, consequently, no particular emphasis may be placed in either the magnitude or the sign of the respective estimated values.

Table A. REGRESSION RESULTS FOR AIRFRAMES, SHOWING THE EFFECT OF EXPLANATORY VARIABLES ON UNIT COST*

Aircraft Model	Constant	Cumulative Output (ln Y)	Lot Size (ln L)	Production Rate (R)	Model Change Dummy (D1)	Model Change Dummy (D2)	Model Change Dummy (D3)	Model Change Dummy (D4)	Additional Statistics
Attack Aircraft									
AD	3.031 (.180) 16.86	-.329 (.028) -11.91							.721 .309 55
(Y<470)	3.904 (.087) 44.86	-.552 (.019) -29.52			1.157 (.223) 5.20				.942 .149 49
(Y≥470)	.545 (.479) 1.14	.158 (.079) 2.09	-.253 (.070) -3.52		-.566 (.320) -1.77	.786 (.314) 2.51			
A-4	3.686 (.148) 24.91	-.350 (.023) -14.85							.843 .270 41
(Y<800)	3.939 (.086) 45.79	-.345 (.032) -10.685	-.114 (-.053) -2.14		.392 (.025) 1.60				.981 .104 33
(Y≥800)	-4.048 (.834) -4.85	.702 (.124) 5.65	.099 (.050) 1.97		2.001 (.080) 2.51	2.736 (.385) 7.11	-.240 (.070) -3.41		
A-3	2.597 (.144) 24.93	-.460 (.034) -13.64							.930 .180 14
	3.828 (.214) 17.91	-.419 (.044) -9.47	-.175 (.119) -1.47		.455 (.426) 1.07				.941 .179 12

(continued on next page)

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*Dependent variable is ln man-hours per pound. In the final column, the top line of each set of three is R^2 (coefficient of determination); the middle line, the standard error of estimate; and the bottom line, the degrees of freedom. In the other columns of figures, the top line of each set of three is the coefficient of the variable; the middle line, the standard error of the coefficient; and the bottom line, the t-value of the coefficient.

Table A. (continued)

Aircraft Model	Constant	Cumulative Output (ln Y)	Lot Size (ln L)	Production Rate (R)	Model Change Dummy				Additional Statistics
					(D1)	(D2)	(D3)	(D4)	
Bombers									
B-52, Seattle	2.4[illegible] (.[illegible]) 37.24	-.336 (.015) -22.98							.912 .133 51
B-52H, Wichita	1.288 (.039) 32.79	-.231 (.013) -22.45							.967 .044 17
	1.458 (.098) 14.88	-.231 (.010 -24.03		-.109 (.058) -1.87					.972 .042 16
B-58	4.053 (.039) 105.05	-.514 (.011) -47.64							.978 .081 52
	3.982 (.049) 81.09	-.488 (.016) -30.96		-.050 (.023) -2.19					.979 .079 51
B-52,* Wichita	2.098 (.036) 57.81	-.310 (.009) -33.76							.977 .070 27
	2.081 (.037) 55.78	-.256 (.028) -9.34		-.090 (.056) -1.62					.978 .070 26
B-52G, Wichita	2.49 (.033) 68.53	-.425 (.008) 50.57							.990 .063 27
	2.604 (.041) 63.65	-.423 (.007) -62.68		-.065 (.016) -3.99					.993 .051 26
Cargo Aircraft									
C-130	2.691 (.164) 16.44	-.365 (.032) -11.47							.846 .194 24
	3.244 (.117) 27.76	-.349 (.014) -24.10	-.242 (.046) -5.21		.904 (.178) 5.09				.978 .076 22

(continued on next page)

*All models except G and H.

Table A. (continued)

Aircraft Model	Constant	Cumulative Output (lnY)	Lot Size (lnL)	Production Rate (R)	Model Change Dummy (D1)	(D2)	(D3)	(D4)	Additional Statistics
C-123	2.079 (.143) 14.53	-.352 (.030) -11.68							.872 .202 20
	2.462 (.143) 17.28	-.293 (.027) -10.92	-.263 (.064) -4.08						.932 .151 19
C-124	2.235 (.114) 20.25		-.480 (.039) -12.34						.884 .178 20
	2.250 (.125) 18.07	-.054 (.172) -.317	-.408 (.289) -1.41		.455 (.358) 1.27				.895 .179 18
KC-135	2.722 (.061) 44.94	-.420 (.011) -37.25							.952 .143 70
	2.629 (.056) 47.07	-.452 (.012) -38.46		.134 (.027) 4.89					.964 .125 69
C-119	1.756 (.051) 34.56	-.272 (.009) -29.22							.952 .100 43
	1.777 (.055) 32.58	-.256 (.018) -14.18	-.037 (.035) -1.04						.953 .099 42
C-82A	3.084 (.121) 25.55	-.483 (.027) -17.82							.964 .104 12
Fighters									
F-100	2.791 (.238) 11.73	-.301 (.038) -7.95							.657 .374 33
	3.056 (.095) 32.12	-.265 (.020) -13.32	-.16 (.039) 4.28		1.336 (.257) 5.21	1.833 (.247) 7.42	1.941 (.263) 7.38		.969 .120 29

(continued on next page)

Table A. (continued)

Aircraft Model	Constant	Cumulative Output (ln Y)	Lot Size (ln L)	Production Rate (R)	Model Change Dummy (D1)	(D2)	(D3)	(D4)	Additional Statistics
F-89	2.523 (.172) 14.67	-.244 (.032) -7.68							.670 .237 29
	2.499 (.097) 25.66	-.252 (.018) -13.96				1.937 (.245) 7.91			.898 .134 28
F-94	1.743 (.139) 12.53	-.212 (.029) -7.29							.829 .141 11
	1.528 (.206) 7.40	-.268 (.050) -5.36	.139 (.102) 1.35						.855 .136 10
F-86	2.816 (.136) 20.75	-.326 (.021) -15.48							.951 .247 42
	3.138 (.100) 31.42	-.187 (.023) -8.00	-.317 (.043) -7.4[illegible]						.935 .165 41
FJ-2	3.823 (.204) 18.76		-.707 (.056) -12.62						.919 .251 14
	3.572 (.098) 36.30	-.396 (.050) -7.89	-.118 (.079) -1.49		1.545 (.313) 4.94				.987 .107 12
F-0A	3.376 (.161) 20.93	-.375 (.025) -15.25							.921 .188 20
	2.774 (.175) 15.89	-.422 (.020) -20.85	.208 (.046) 4.57						.961 .136 19
F-2H	3.205 (.094) 35.34	-.386 (.019) -20.11							.953 .129 20
	3.605 (.149) 24.21	-.296 (.044) -6.76	-.025 (.011) -2.27		.748 (.206) 3.64	.502 (.196) 2.56			.967 .099 17

(continued on next page)

Table A. (continued)

Aircraft Model	Constant	Cumulative Output (ln Y)	Lot Size (ln L)	Production Rate (R)	Model Change Dummy (D1)	(D2)	(D3)	(D4)	Additional Statistics
F-80	3.358 (.085) 39.6	.430 (.013) -32.87							.977 .189 26
	3.428 (.087) 39.27	-.418 (.015) -28.28	-.044 (.027) -1.60		.492 (.194) 2.58				.984 .103 24
F-8	3.312 (.057) 58.28	-.362 (.010) -36.99							.972 .086 32
	3.165 (.067) 47.43	-.391 (.012) -31.70	.093 (.028) 3.29						.983 .077 31
F-101	3.040 (.044) 69.27	-.339 (.010) -33.93							.986 .074 15
	3.050 (.043) 70.87	-.292 (.034) -8.52	-.072 (.050) -1.44						.988 .071 15
F-3	3.583 (.064) 55.28	-.423 (.012) -34.37							.986 .064 17
Miscellaneous Aircraft									
O-1A,B	.312 (.235) 1.33	-.077 (.031) -2.45							.070 .249 80
	1.102 (.219) 5.02	-.178 (.028) -6.39	-.056 (.013) -4.41		2.662 (.286) 9.31				.612 .163 38
P-3	2.339 (.054) 43.57	-.338 (.012) -29.14							.977 .075 19
	2.550 (.076) 33.60	-.272 (.022) -12.50	-.196 (.058) -3.38						.986 .060 18

(concluded on next page)

Table A. (concluded)

Aircraft Model	Constant	Cumulative Output (ln Y)	Lot Size (ln L)	Production Rate (R)	Model Change Dummy				Additional Statistics
					(D1)	(D2)	(D3)	(D4)	
Trainers									
T-33	1.235 (.087) 14.14	-.155 (.012) -12.70							.726 .171 61
	1.088 (.085) 12.88	-.203 (.016) -13.01	.117 (.028) 4.25						.786 .153 60
T-28	2.530 (.081) 31.29	-.324 (.015) -22.07							.964 .133 18
	2.650 (.071) 37.21	-.212 (.033) -6.46	-.192 (.052) -3.66						.979 .105 17
T-37A,B	3.390 (.055) 61.28	-.445 (.010) -42.59							.991 .063 17
	3.476 (.093) 37.43	-.426 (.019) -22.18	-.052 (.045) -1.14						.991 .062 16

APPENDIX B

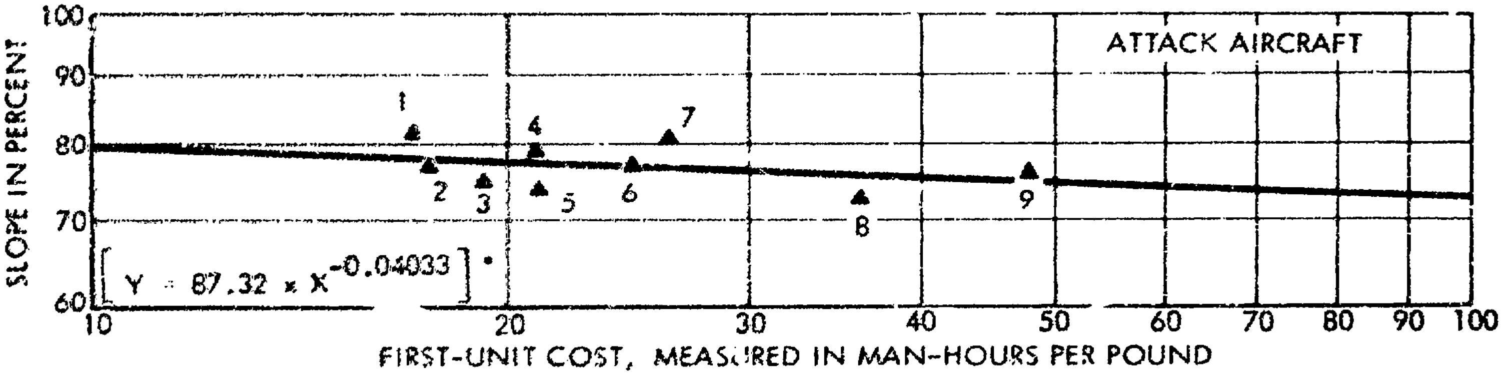
FIGURES SHOWING RELATIONSHIP BETWEEN FIRST-UNIT COST AND PROGRESS-CURVE SLOPE

Appendix B

FIGURES SHOWING RELATIONSHIP BETWEEN FIRST-UNIT COST AND PROGRESS-CURVE SLOPE

Regression equations were run to determine the correlation between first-unit cost and slope. Incorporated in this analysis of 78 aircraft are data obtained from *Aircraft Learning Curves*, Naval Air Systems Command (June 1969) [7]. The aircraft are listed in Appendix C and include attack aircraft (Figure B-1), bombers (Figure B-2), cargo aircraft (Figure B-3), helicopters (Figure B-4), trainers (Figure B-5), and fighters (Figure 6 in the main report).

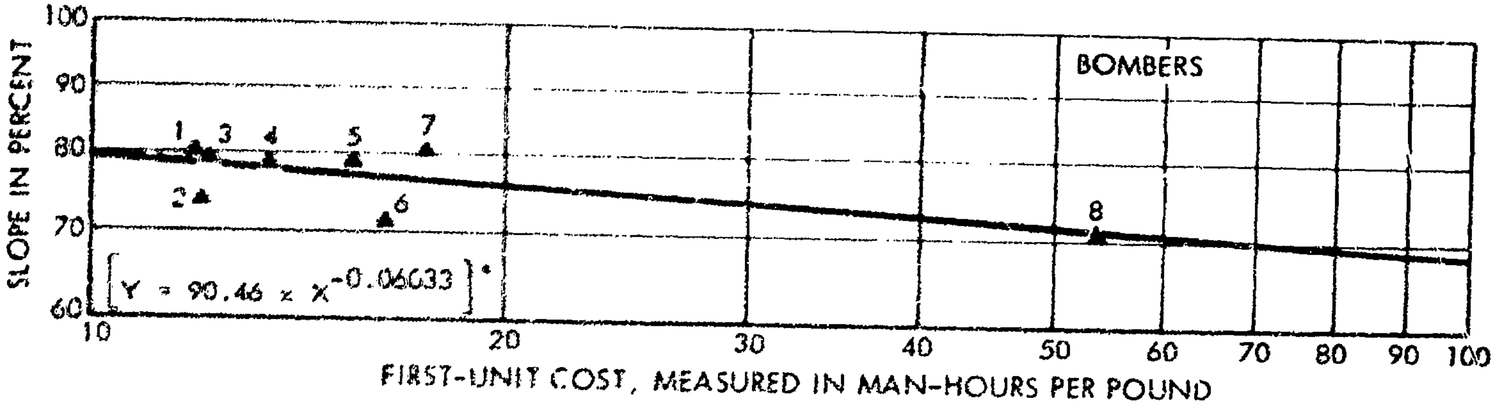
Each figure in this appendix presents a set of plots of progress-curve slopes (in percent) versus first-unit cost, the fitted regression line, and the regression-line equation. The results of that equation indicate that first-unit cost and slope are negatively related (i.e., the higher the first-unit cost the steeper the progress-curve slope--a smaller percentage slope is steeper). In other words, those programs with a higher initial cost have a greater percentage reduction in cost as output increases.



LEGEND:
1 = AJ-2, 2P
2 = A-7A
3 = RA-3B, EA-3B, TA-3B
4 = A-1G, A-1E, EA-1E
5 = A-2A
6 = A-5A
7 = A-6A, EA-6A, EA-6B
8 = A-3A, A-3B
9 = A-4 SERIES

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION $(R^2) = 0.14$; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

Figure B-1. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: ATTACK AIRCRAFT

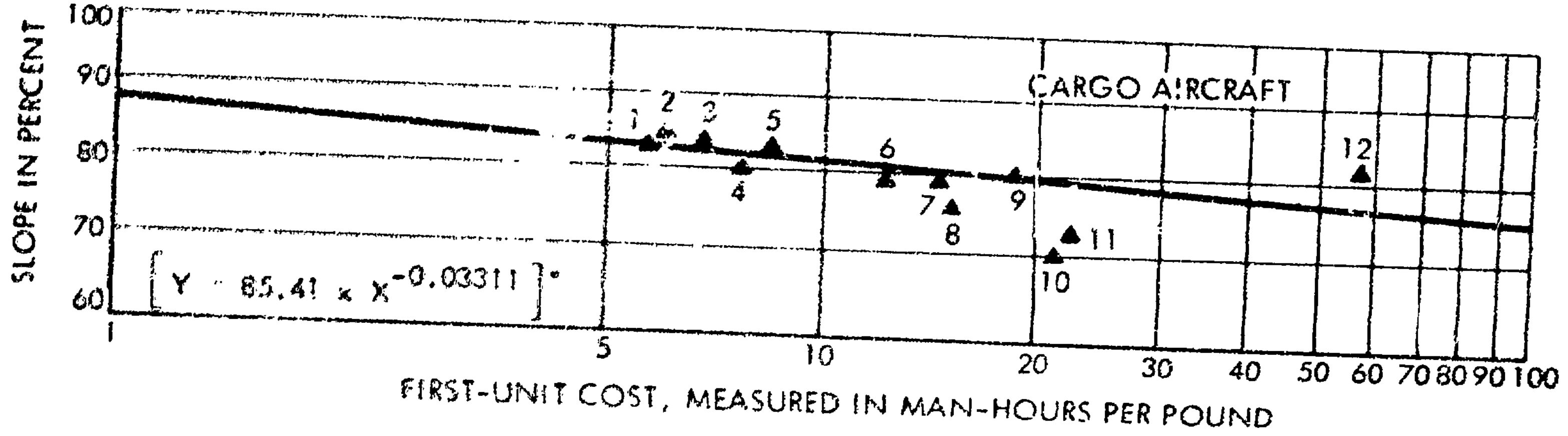


LEGEND:

1 = B-45A, C/RB-45C
2 = B-52G
3 = B-50A, B, D
4 = B-47B, E
5 = B-36A, B, D, F, H, J/RB-36B
6 = RB-66C/WB-66D
7 = B-57A, B, C, E/RB-57A
8 = YB/YRB-58A

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION (R^2) = 0.37; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

Figure B-2. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: BOMBERS

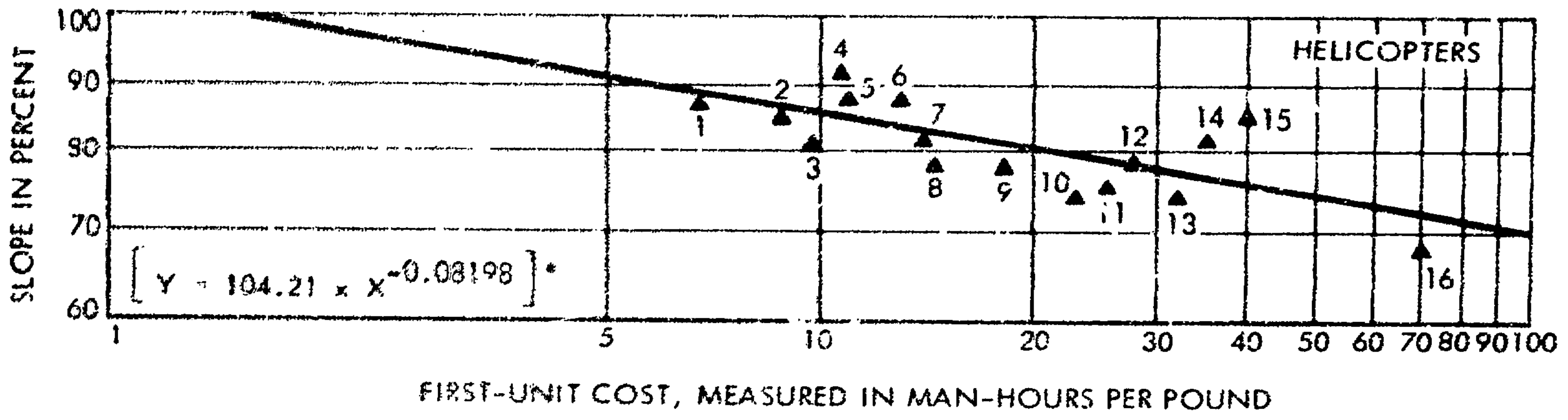


LEGEND:

1 = C-119B,C,F,G/R4Q-1,2
2 = RC-121D/EC-121K/WC-121N
3 = C-131A,B,D
4 = C-123B
5 = C-124A,C
6 = YC-122A,B,C
7 = C-130A,B
8 = KC-135A
9 = R3Y-1,2
10 = C-133A,B
11 = C-82A
12 = C-97A,C/KC-97E,F,G

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION (R^2) = 0.42; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

Figure B-3. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: CARGO AIRCRAFT



LEGEND:

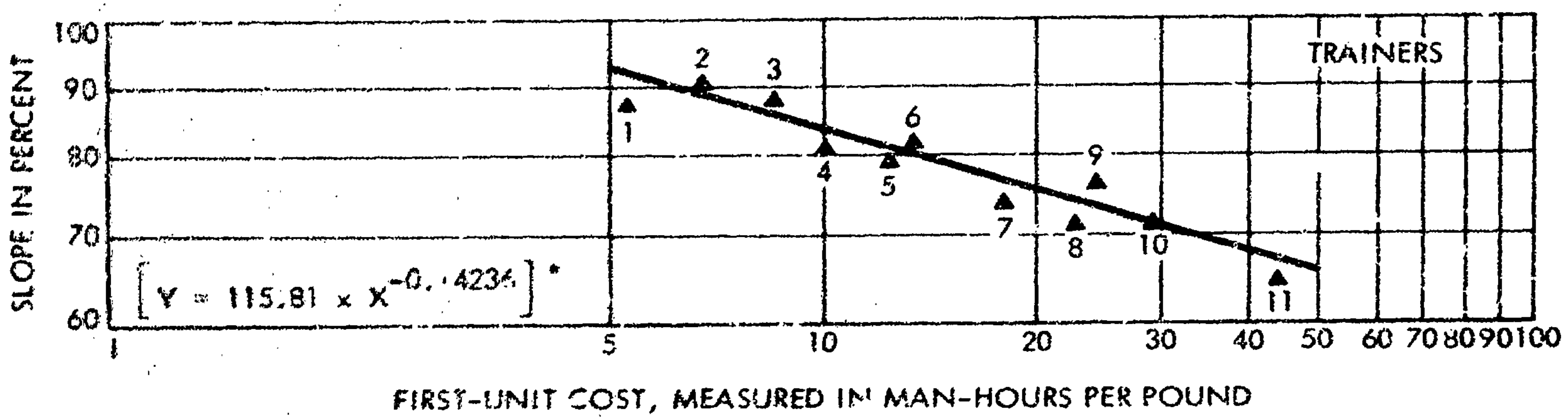
1 = OH-23D
2 = NH-41A
3 = H-53 SERIES
4 = YUH-1D, UH-1D
5 = H-19 SERIES
6 = H-34 SERIES
7 = CH-21B/C, V-42/43/44
8 = H-47 SERIES

9 = UH-2A
10 = H-46 SERIES
11 = CH-37A/CH-37C, HR2S-1W
12 = SH-3A, VH-3A, S-61
13 = HO5S-1
14 = UH-25B/H-25A
15 = TH-43E
16 = OH-43D, UH-43C, HH-43A

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION $(R^2) = 0.52$; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

[illegible]

Figure B-4. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: HELICOPTERS



LEGEND:

1 = T-35A
2 = T-29A,B,C,D
3 = T-28B,C
4 = T-34A,B
5 = T-28A
6 = TF-102A
7 = T-1A
8 = T-2A
9 = T-38A
10 = T-37A,B
11 = T-39A,B

* REGRESSION EQUATION HAS A COEFFICIENT OF DETERMINATION (R^2) = 0.92; Y = SLOPE (IN PERCENT); X = FIRST-UNIT COST (IN MAN-HOURS PER POUND).

Figure B-5. PROGRESS-CURVE SLOPE VERSUS FIRST-UNIT COST: TRAINERS

APPENDIX C

TABLE ILLUSTRATING EXPLANATORY POWER OF PROGRESS CURVES OF 78 AIRCRAFT

Appendix C

TABLE ILLUSTRATING EXPLANATORY POWER OF PROGRESS CURVES OF 78 AIRCRAFT

This appendix lists the 78 aircraft used for analyses in Appendix B and Figure 4 of the Executive Summary (or Figure 6 of the full report). The "estimated first-unit costs" and progress-curve slopes were obtained from *Aircraft Learning Curves* [7]. This source derived these progress-curve results by fitting regression lines through actual cost (in man-hours per pound) and cumulative output data for each system.

Note that there are some differences between the progress-curve parameters and coefficients of determination (for a few aircraft) shown in Tables A and C. The reason for the difference is that the progress curves shown in Table A were derived from all the cost-quantity data for a given aircraft, while the progress curves shown in Table C were derived (by the authors of *Aircraft Learning Curves* [7]) by using data that had eliminated all the cost-quantity data associated with major model changes.

The very high R^2's (coefficients of determination) that resulted from this procedure indicate the high explanatory power of the progress curves.

Table C. ILLUSTRATION OF EXPLANATORY POWER OF PROGRESS CURVES

Plot-Point Number	Aircraft	Estimated First-Unit Cost (direct man-hours per pound)	Progress-Curve Slope	R^2 (Coefficient of Determination)
	Attack Aircraft			
1	AJ-2, 2P	17.02	81.2	.87
2	A-7A	17.67	76.5	.99
3	RA-3B, EA-3B, TA-3B	19.05	75.2	.96
4	A-1G, A-1E, EA-1E	20.81	78.3	.76
5	A-2A	20.93	73.9	.98
6	A-5A	24.61	77.5	.95
7	A-6A, EA-6A, EA-6B	25.97	80.6	.99
8	A-3A/A-3B	36.07	72.8	.93
9	A-4 SERIES	47.67	75.7	.98
	Bombers			
1	B-45A, C/RB-45C	11.85	80.0	.82
2	B-52G	12.06	74.5	.99
3	B-50A,B,D	12.18	78.4	.92
4	B-47B,E	13.37	78.0	.97
5	B-36A,B,D,F,H,J/RB-36B	15.44	78.5	.92
6	RB-66C/WB-66D	16.40	71.3	.98
7	B-57A,B,C,E/RB-57A	17.44	80.0	.94
8	YB/YRB-58A	53.43	71.0	.97
	Cargo Aircraft			
1	C-119B,C,F,G/R4Q-1,2	5.75	82.8	.95
2	RC-121D/EC-121K/WC-121N	6.07	82.8	.97
3	C-131A,B,D	6.97	82.1	.76
4	C-123B	7.89	78.5	.87
5	C-124A,C	8.32	82.2	.88
6	YC-122A,B,C	11.82	77.5	.76
7	C-130A,B	14.64	77.7	.85
8	KC-135A	15.21	74.8	.95
9	R3Y-1,2	18.60	81.0	.89
10	C-133A,B	21.32	70.1	.98
11	C-82A	21.71	71.6	.96
12	C-97A, C/KC-97E,F,G	57.18	82.2	.86

(continued on next page)

Table C. (continued)

Plot-Point Number	Aircraft	Estimated First-Unit Cost (direct man-hours per pound)	Progress-Curve Slope	R^2 (Coefficient of Determination)
	Helicopters			
1	OH-23D	6.62	88.4	.92
2	HH-41A	8.75	86.3	.86
3	H-53 SERIES	9.72	81.8	.95
4	YUH-1D, UH-1D	10.75	91.7	.86
5	H-19 SERIES	11.38	89.3	.78
6	H-34 SERIES	12.75	88.6	.91
7	CH-21B/C, V-42/43/44	14.26	82.4	.85
8	H-47 SERIES	14.43	80.3	.93
9	UH-2A	23.07	79.6	.94
10	H-46 SERIES	23.86	75.4	.78
11	CH-37A/CH-37C/HR2S-1W	25.59	77.8	.98
12	SH-3A/VH-3A/S-61	27.61	79.5	.94
13	HO5S-1	32.36	75.1	.90
14	UH-25B/H-25A	35.18	82.5	.84
15	TH-43E	40.44	86.3	.81
16	OH-43D, UH-43C, HH-43A	70.24	69.8	.79
	Trainers			
1	T-35A	5.19	88.5	.98
2	T-29A,B,C,D	6.70	90.2	.31
3	T-2B,C	9.53	88.1	.93
4	T-34A,B	10.24	81.2	.88
5	T-28A	12.30	80.0	.97
6	TF-102A	13.45	82.9	.90
7	T-1A	18.04	74.4	.98
8	T-2A	23.18	72.8	.98
9	T-38A	24.13	75.9	.97
10	T-37A,B	29.46	73.5	.99
11	T-39A,B	43.76	65.8	.99

(concluded on next page)

Table C. (concluded)

Plot-Point Number	Aircraft	Estimated First-Unit Cost (direct man-hours per pound)	Progress-Curve Slope	R^2 (Coefficient of Determination)
	Fighters			
1	F-89A,B,C,D,H	12.31	84.6	.69
2	F-4U-5N	13.59	79.2	.98
3	F-86F	14.36	80.5	.98
4	F-100C,D	18.18	75.0	.86
5	F-94C	18.48	76.5	.98
6	F-101B	20.51	79.3	.99
7	F-105D	21.91	80.0	.99
8	F-104A,C	22.38	78.7	.95
9	F-1E/AF-1E	23.06	73.9	.99
10	F2H-1,2,2N,2P	27.66	76.6	.95
11	F-8A,C,D	27.90	77.5	.98
12	F-80A,B,C	28.13	74.4	.96
13	F-10A/B	28.89	74.2	.92
14	FJ-2	34.45	71.2	.98
15	F-3B/MF-3B,F-3C,F-3H-1	35.08	74.6	.99
16	F-4 SERIES	35.38	78.7	.93
17	FH-1	35.68	74.5	.98
18	XF7U-1/F7U-1,3,3M,3P	38.17	74.5	.88
19	F-106A	38.27	71.7	.94
20	F-102A	39.09	75.3	.96
21	RF-84F	40.12	72.6	.98
22	F-6A	61.20	74.2	.99

APPENDIX D

TABLES SUMMARIZING EMPIRICAL STUDIES OF RELATIONSHIP BETWEEN PRODUCTION RATE AND UNIT COST

Appendix D

TABLES SUMMARIZING EMPIRICAL STUDIES OF RELATIONSHIP BETWEEN PRODUCTION RATE AND UNIT COST

This appendix presents a list of empirical studies done on cost curves. Extracted from a survey article by Walters [19] in *Econometrica* (1963), the tables illustrate results obtained in measuring the effect of production rate on cost when no progress-curve effects are explicitly taken into account. The tables present the relationship between cost and production rate when time series, cross section, engineering, and survey data were used. These tables indicate that an increase in the production rate may either reduce, leave unaffected, or increase unit cost. The interpretation of these results in terms of a U-shaped cost curve is given by Appendix E.

Table D-1. RESULTS OF STUDIES OF COST CURVES, GENERAL INDUSTRY STUDIES*

Reference	Author(s) (Year)	Industry	Type of Data	Time Period	Result
[34]	Eiteman and Guthrie (1952)	Manufacturing	Q	S	Marginal cost below average cost at all outputs below "capacity."
[35]	Hall and Hitch (1939)	Manufacturing	Q	S	Majority have marginal cost decreasing.
[36]	Lester (1946)	Manufacturing	Q	S	Decreasing average variable cost to capacity.
[37]	Bain (1956)	Manufacturing	Q	L	Small economies of scale of multiplant firms.
[38]	Moore (1959)	Manufacturing	E	L	Economies of scale generally.
[39]	T.N.E.C. (1941)	(Various industries)	CS	L	Small or medium-size plants usually have lowest costs. Blair (1942) [40] draws different conclusions.

*Q = questionnaire; E = engineering data; CS = cross section; L = long-run; and S = short-run.

Table D-2. RESULTS OF STUDIES OF COST CURVES, INDUSTRY STUDIES*

Reference	Author(s) (Year)	Industry	Type of Data	Time Period	Result
[41]	Johnston (1960)	Multiple product	TS	S	"Direct" cost is linearly related to output. Marginal cost constant.
[42]	Dean (1936)	Furniture	TS	S	Marginal cost constant. Short-run average cost "failed to rise."
[43]	Dean (1941)	Leather belts	TS	S	Significantly increasing marginal cost. Rejected by Dean.
[44]	Dean (1941)	Hosiery	TS	S	Marginal cost constnat. Short-run average cost "failed to rise."
[45]	Dean (1942)	Department store	TS	S	Marginal cost declining or constant.
[46]	Ezekiel and Wylie (1941)	Steel	TS	S	Marginal cost declining, but large standard errors.
[47]	Yntema (1940)	Steel	TS	S	Marginal cost constant.
[48]	Ehrka (1933)	Cement	TS	S	Ehrke interprets as constant marginal cost. Apel (1948) [49] argues that marginal cost is increasing.
[50]	Nordin (1947)	Light plant	TS	S	Marginal cost increasing.
[51]	Alpert (1959)	Metal	E	L	Economies of scale to 80,000 pounds per month; then constant returns.
[52]	Dean and James (1942)	Shoe stores	CS	L	Long-range average cost is U-shaped (interpreted as not due to diseconomies of scale).
[53]	Holton (1956)	Retailing (Puerto Rico)	E	L	Long-range average cost is L-shaped. But Holton argues that inputs of management may be undervalued at high outputs.

*TS = time series; E = engineering data; CS = cross section; S = short-run; and L = long-run.

Table D-3. RESULTS OF STUDIES OF COST CURVES, PUBLIC UTILITIES*

Reference	Author(s) (Year)	Industry	Type of Data	Time Period	Result
		Electricity			
[41]	Johnston (1960)	U.K.	TS	S	Short-run average cost falling, then flattening with a tendency toward constant marginal cost up to capacity.
[54]	Lomax (1952)	U.K.	CS	L	Long-range average cost of production declining (no analysis of distribution).
[41]	Johnston (1960)	U.K.	CS	L	Long-range average cost of production declining (no analysis of distribution).
[55]	McNulty (1955)	U.S.A.	CS	L	Average costs of administration constant.
[56]	Nerlove (1961)	U.S.A.	CS	L	Long-range average cost (excluding transmission costs) declining, then showing signs of increasing.
		Railways			
[57]	Broster (1938)	U.K.	TS	S	Operating cost per unit of output falling.
[58]	Borts (1952)	U.S.A.	CS	L	Long-range average cost either constant or falling.
[59]	Borts (1960)	U.S.A.	CS	L	Long-range average cost increasing in East, decreasing in South and West.
[60]	Mansfield and Wein (1958)	U.K.	E	L	Marginal cost constant.
		Other			
[41]	Johnston (1960)	Road passenger transport (U.K.)	TS	S	Short-run average cost decreasing.
[61]	Lomax (1951)	Gas (U.K.)	CS	L	Long-range average cost of production declining (no analysis of distribution).
[62]	Gribbin (1953)	Gas (U.K.)	CS	L	Long-range average cost of production declining (no analysis of distribution).
[41]	Johnston (1960)	Coal (U.K.)	CS	L	Wide dispersion of costs per ton.
[41]	Johnston (1960)	Road passenger transport (U.K.)	CS	L	Long-range average cost either falling or constant.
[41]	Johnston (1960)	Life Assurance	CS	L	Long-range average cost declining.

*TS = time series; CS = cross section; E = engineering data; S = short-run; and L = long-run.

APPENDIX E

SIMPLIFIED THEORETICAL DISCUSSION OF RELATIONSHIP OF PRODUCTION RATE, PROGRESS CURVES, AND UNIT COST

Appendix E

SIMPLIFIED THEORETICAL DISCUSSION OF RELATIONSHIP OF PRODUCTION RATE, PROGRESS CURVES, AND UNIT COST

It is useful to present a simplified theoretical structure that relates production rate to unit cost. This theoretical framework is consistent with that of standard economic texts. It will be demonstrated that this theoretical structure leads to a U-shaped relationship between unit cost and production rate. A U-shaped cost curve explains empirical results that sometimes show an increase and sometimes show a decrease in unit cost as production rate is increased. A brief and simplified integration of cost curves and progress curves also is presented in this appendix.

First, let us postulate a simple production function with constant returns to scale. A production function relates the rate of output to the amount of labor and capital used in a given time period. "Constant returns to scale" means that if labor and capital are doubled, then the rate of output is doubled. We use constant returns to scale to simplify the discussion of the theoretical relationship between production rate and cost. The qualitative results that will be presented for constant returns to scale also apply to decreasing or (moderately) increasing returns to scale.

We will use a Cobb-Douglas production function (CDPF)--i.e.,

$$X = AL^{\alpha}K^{\beta} \qquad (\alpha>0, \beta>0, \alpha+\beta=1) \; , \qquad \text{(E-1)}$$

where

X = quantity produced per unit of time;

L = units of labor input (i.e., index number of man-hours);

K = units of capital input (i.e., index number of machine-hours); and

A, α, β = constants.

More complex production functions could be presented; they would not change the conclusions we will derive from a CDPF, but they would complicate the mathematics and the discussion unnecessarily. The amount of capital K can be treated as a fixed factor of production (i.e., the amount of plant and equipment available can be considered in fixed supply for short periods of time). The amount of labor, however, can be considered a variable factor of production (i.e., the amount available to a particular product can be increased or decreased in a plant within short periods of time).

Therefore, we can rewrite the CDPF to reflect these assumptions:

$$X = BL^{\alpha} , \tag{E-2}$$

where $B = AK^{\beta} =$ constant .

Total cost equals the sum of labor cost and capital cost--i.e.,

$$C = wL + kK , \tag{E-3}$$

where

C = total cost;

w = wage rate;

L = units of labor input (same L as in Eq. E-1);

k = price of capital inputs; and

K = units of capital input (same K as in Eq. E-1).

Since capital is here treated as a fixed factor of production, capital costs are fixed; the total cost equation (E-3) therefore can be rewritten as

$$C = wL + F , \qquad \text{(E-4)}$$

where F = fixed costs = constant. Substituting the rate of production X of Equation (E-2) for units of labor input L in Equation (E-4) yields

$$C = \frac{w}{B^{1/\alpha}} X^{1/\alpha} + F . \qquad \text{(E-5)}$$

Average cost can be derived from Equation (E-5) by dividing both sides of that equation by the rate of production X:

$$\frac{C}{X} = \frac{w}{B^{1/\alpha}} X^{\frac{1}{\alpha} - 1} + \frac{F}{X} , \qquad \text{(E-6)}$$

where $\frac{C}{X}$ = average cost. For simplicity, we rewrite Equation (E-6) as

$$\frac{C}{X} = qX^{\gamma} + \frac{F}{X} \qquad (\gamma > 0) , \qquad \text{(E-7)}$$

where $q = \frac{w}{B^{1/\alpha}}$ and $\gamma = \frac{1}{\alpha} - 1$.

If average cost C/X is plotted against production rate X using Equation (E-7), then a U-shaped average cost curve emerges.[1]

---

[1] To derive a marginal or unit-cost equation, Equation (E-7) needs to be differentiated with respect to X. The resulting marginal cost equation is

$$\frac{dC}{dX} = q\gamma X^{\gamma - 1} - \frac{F}{X^2} ,$$

where $\frac{dC}{dX}$ = marginal or unit cost. Theoretically, the marginal (rather than the average) equation should be used for purposes of decision-making. As a practical matter, decisions based on average cost usually will be close to those based on marginal cost.

The precise shape of the curve, whether it is nearly symmetrical or skewed to the right or left, depends on the numerical values for q, γ, and F. There are four obvious conclusions that can be drawn from a U-shaped cost curve:

(1) Whether increasing or decreasing the production rate will lower average cost depends on whether the rate of production is "too small" or "too large." Too small or too large a production rate is only used here in relation to minimum average (or marginal) cost. "Too small" or "too large" does *not* imply that a firm is economically inefficient or that it is not maximizing profit.

(2) An empirical analysis that tries to fit a monotonic relationship (e.g., linear, log-linear) between average cost and production rate across several models of a product (e.g., models of aircraft) is most likely not to come up with any significant relationship between cost and production rate (unless there is a strong systematic bias towards too low or too high a production rate among models of a product). If a significant relationship did occur, then a question as to whether the sample was representative and statistically unbiased would occur.

(3) An empirical analysis that fits a monotonic relationship (e.g., linear or log-linear) between average cost and production rate for a specific model in a time-series analysis is not likely to come up with a significant relationship when the production rate is sometimes "too high" and sometimes "too low."

(4) If the rate of production is systematically either too low or too high for a particular model at different points in time, then either a negative or a positive relationship will show up between production rate and average (or marginal) cost.

Let us further examine Equation (E-7). If we consider two plants that have the same A, α, and B parameters but one with twice as much capital as the other, then what will the cost curve of the smaller plant be relative to the larger plant?

For the smaller plant, we will use Equation (E-7) to represent its average cost:

$$\frac{C}{X} = qX^{\gamma} + \frac{F}{X} . \qquad \text{(E-7)}$$

The cost of the plant twice as large would be represented by

$$\frac{C}{X} = qX^{\gamma} + \frac{2F}{X} . \qquad \text{(E-8)}$$

Figure E represents the average cost curves for smaller and larger plants. The production rate required to achieve a minimum average (or marginal) cost for the larger plant is twice that of the smaller plant. Thus, in a procurement program that requires small cumulative quantities with (probably) low rates of scheduled delivery, a small plant will achieve lower costs than a large plant; conversely, for large cumulative quantities with (probably) high rates of scheduled delivery, a large plant will achieve lower costs than a small plant. If there are economies of scale (doubling labor and capital more than doubles output) or diseconomies of scale (doubling labor and capital less than doubles output), then the minimum cost will be different for the large plant and the small plant. With economies of scale, the theoretical minimum cost will be lower for the large plant than for the small plant; with diseconomies of scalo, the converse is true. These results hold, provided that the progress-curve parameters are the same for large and small plants.

To obtain a progress curve from a production function, let us assume for simplicity that the amount of both labor and capital used in a plant remain fixed over time. Furthermore, let us assume that "disembodied" technical progress is occurring at a constant rate over time. "Disembodied" technical progress means that the rate of technological progress that occurs is independent of the level of labor or capital used. The exist-

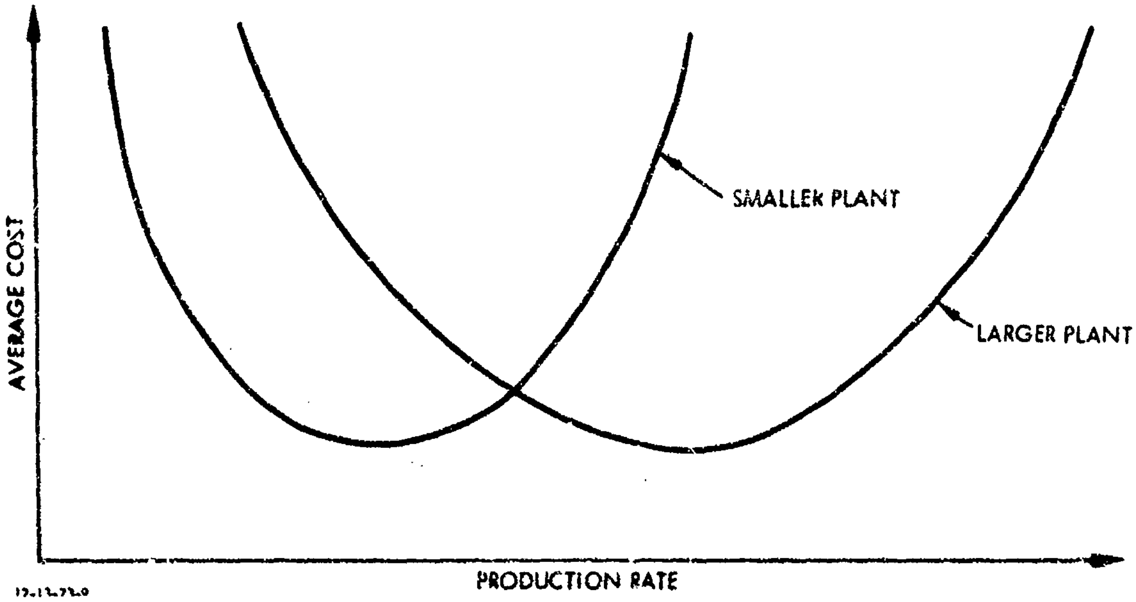


Figure E. COST CURVES FOR TWO SIZES OF PLANTS

ence of disembodied technical progress is consistent with learning by labor. For example, let

$$\hat{L} = atL \;, \qquad \text{(E-9)}$$

where

$\hat{L}$ = the amount of labor-equivalent units (one labor-equivalent unit produces a constant amount of output per unit of time);

L = the amount of labor in man-hours per unit of time;

t = time; and

a = constant.

For the reader's convenience, we repeat equation (E-2), which is based on a Cobb-Douglas production function:

$$X = BL^a \;. \qquad \text{(E-2)}$$

Equation (E-2) is consistent with Equation (E-9) only when

$$B = (ct)^a \;,$$

where c = a constant. But it is precisely the case when $B = (ct)^a$ that disembodied technical progress exists.

Cumulative output Y can be obtained from Equation (E-2) by taking the integral of this equation with respect to time.

$$Y = \int X dt = \int (ct)^{\alpha} L^{\alpha} dt = \frac{c^{\alpha} L^{\alpha} t^{2\alpha}}{2} \ . \tag{E-10}$$

Dividing Equation (E-10) by L and taking the inverse yields

$$\frac{L}{Y} = \frac{2L^{1-\alpha} t^{-2\alpha}}{c^{\alpha}} \ . \tag{E-11}$$

The term L/Y is the average cost, in terms of man-hours (per unit of time) per cumulative unit.

Taking logarithms of both sides of Equation (E-11) gives

$$\ln\left(\frac{L}{Y}\right) = h - 2\alpha \ln t \ , \tag{E-12}$$

where $h = \ln\left(\frac{2L^{1-\alpha}}{c^{\alpha}}\right) =$ constant. Taking logarithms of both sides of Equation (E-10) yields

$$\ln Y = k + 2\alpha \ln t \ , \tag{E-13}$$

where $k = \ln\left(\frac{c^{\alpha} L^{\alpha}}{2}\right) =$ constant.

Since Y is linearly related to t, the term L/Y can be interpreted as the average cost, in terms of man-hours (per given amount of output) per cumulative unit.

Substituting Equation (E-13) for $\ln t$ in Equation (E-10) gives

$$\ln\left(\frac{L}{Y}\right) = h - \sigma \ln Y \ , \tag{E-14}$$

where $\sigma = \frac{2\alpha}{k+2\alpha}$. Equation (E-14) represents an ordinary log-linear progress curve. This progress curve has been derived directly from a (Cobb-Douglas) production function with disembodied technical progress.

APPENDIX F

THEORETICAL EXAMINATION OF THE POST-COMPETITIVE PROGRESS CURVE

CONTENTS

Appendix F

THEORETICAL EXAMINATION OF THE POST-COMPETITIVE PROGRESS CURVE

This appendix attempts to provide a theoretical basis for the empirical conclusions presented in Chapter IV. It is shown that negotiated sole-source procurement contracts, even if executed after a design competition, can lead to an inefficient, and hence more costly, mix of inputs; and that, due to this inefficiency, subsequent reprocurement of a particular piece of equipment under competitive conditions may result in the contract award going to a different supplier. This latter result can be expected in many cases even after allowing for the cost advantage that the original supplier obtains from the progress-curve effect.

A. ASPR PROFIT WEIGHTS AND INEFFICIENT PRODUCTION

In this section, the incentives provided by the Armed Services Procurement Regulation (ASPR) for the contractors to use efficient production methods will be analyzed. Every negotiated procurement-action requires some form of price or cost analysis, and an important part of the price-negotiation policies and techniques is the calculation of profits. ASPR explicitly states that "It is the policy of the Department of Defense to utilize profit to stimulate efficient contract performance [and that] the aim of negotiation should be to employ the profit motive so as to impel effective contract performance by which overall costs are economically controlled" [3-808.1(a)]. Nevertheless, the way profits are calculated may induce a bias and an inefficiency in the use of certain factors of production. After a brief description of how profits are determined, a theoretical economic analysis of the incentives toward inefficient resource use will be made.

1. Description of Profit Weights and Their Use

ASPR's weighted-guidelines method for establishing profit objectives is designed to tailor profits to the circumstances of each contract by taking into account the contractor's costs, the contractor's assumption of cost risk, his past performance, and other selected factors. Table F, derived from ASPR 3-808.4, lists the various profit factors and weight ranges. For the "Contractor's Input to Total Performance," the contracting officer assigns a profit percentage within the designated weight ranges to each category of contract cost, and multiplies the costs by the specific percentages, to arrive at specific dollar profits. The total dollar profit from all the cost categories is then divided by the total input costs to get the profit objective as a percent of total input costs. To this profit objective is added the additional percentages that allow for the "Contractor's Assumption of Contract Cost Risk," which is primarily based on the type of contract to be granted and the ability of the contractor to pass on increases in costs; "Record of Contractor's Performance"; "Selected Factors," where government-provided inputs would be considered; and "Special Profit Consideration." The sum of these percentages gives the total profit objective.

Because the profit objective varies with the specific procurement, the government hopes to encourage good contractor performance. Although cost risk and the source of the material and financial resources are quite legitimate factors in determining an adequate rate of return, the differential weights attached to the cost categories in "Contractor's Input to Total Performance" can lead to an inefficient combination of inputs. The use of engineering labor gives profits of 9 to 15 percent

Table F. ASPR WEIGHTS

Profit Factors	Weight Ranges
CONTRACTOR'S INPUT TO TOTAL PERFORMANCE	
Direct Materials	
Purchased Parts.	1 to 4%
Subcontracted Items.	1 to 5%
Other Materials.	1 to 4%
Engineering Labor.	9 to 15%
Engineering Overhead	6 to 9%
Manufacturing Labor.	5 to 9%
Manufacturing Overhead	4 to 7%
General and Administrative Expenses.	6 to 8%
CONTRACTOR'S ASSUMPTION OF CONTRACT COST RISK. .	0 to 7%
Type of Contract	
Reasonableness of Cost Estimate	
Difficulty of Contract Task	
RECORD OF CONTRACTOR'S PERFORMANCE	-2 to +2%
Small Business Participation	
Management	
Cost Efficiency	
Reliability of Cost Estimates	
Value Engineering Accomplishments	
Timely Deliveries	
Quality of Product	
Inventive and Developmental Contributions	
Labor Surplus Area Participation	
SELECTED FACTORS	-2 to +2%
Source of Resources	
Government or Contractor Source of Financial and Material Resources	
Special Achievement	
Other	
SPECIAL PROFIT CONSIDERATION....	

of that labor's cost, while use of manufacturing labor yields profits of 5 to 9 percent of that cost; and purchased parts have profit weights of only 1 to 4 percent. If the production facilities must be provided by the contractor and charges for their use are recorded in manufacturing overhead, there is a profit factor of 4 to 7 percent of these amortized costs. In a commercial situation, the firm would normally look at the cost of an input, consider the value of the output that input produces, and choose the relative amounts of all inputs on this basis. The profit in the commercial situation depends on the overall costs and the price that buyers are willing to pay, and the buyers' demand is independent of the method of production. But when the profit rate depends on the use of specific inputs, as in negotiated military procurements, the firm has an incentive to use the inputs with the highest profit weights.

2. Theoretical Analysis

The following discussion may appear to be excessively complex, but a careful theoretical discussion of the incentives facing a firm is needed to indicate how production inefficiencies can arise. Since the study has been unable to get data on production costs that will show the change in costs (rather than prices) as procurements go from negotiated to formally advertised bidding, the discussion will show why costs theoretically should fall. The simple change in incentives from negotiated contracts with weighted profit guidelines to firm fixed-price contracts with no government control over profits can lead to a lower-cost production method.

Figure F-1 describes in graphical terms the determination of the lowest cost (most efficient) method of production. Here let $\bar{Y}$ be a constant amount of output that can be produced with different combinations of the inputs (capital K and labor L). The curvature of this equal-output line shows diminishing

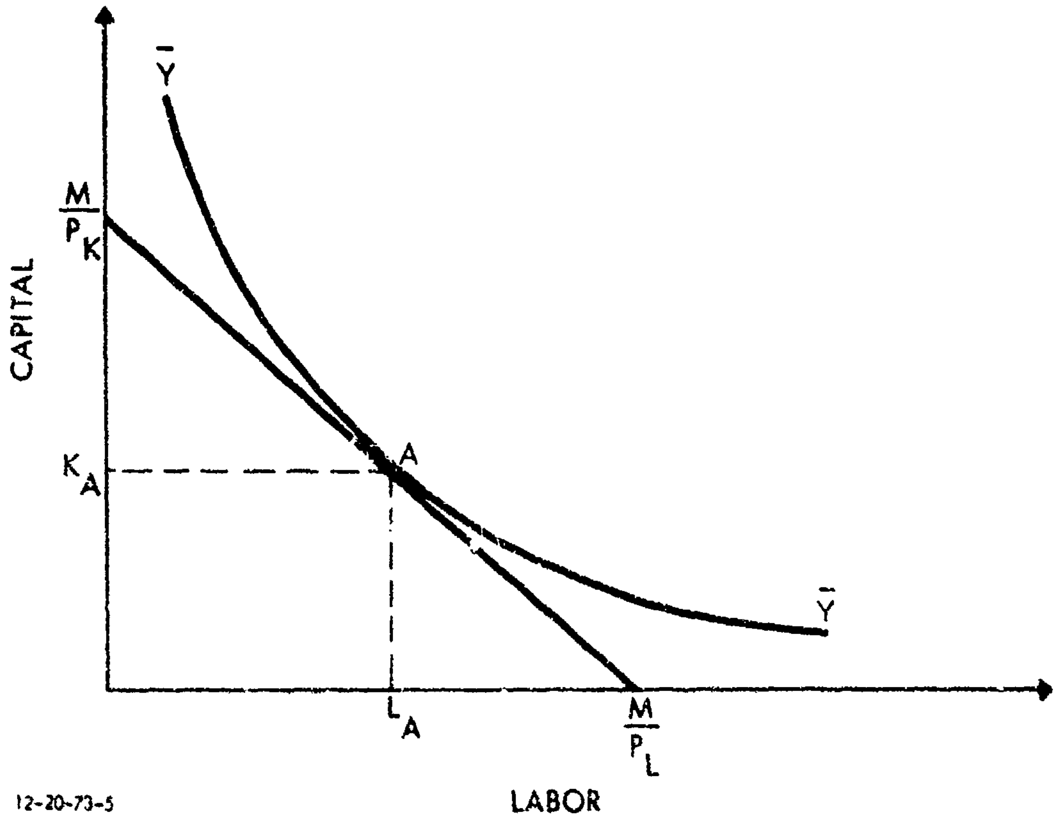


Figure F-1. CHOICE OF MOST EFFICIENT PRODUCTION METHOD

returns in the use of each input, which means that as the firm tries to produce $\bar{Y}$ with less and less capital, larger amounts of labor will have to be substituted. The choice of which combination of K and L to use to produce $\bar{Y}$ will depend on the prices of the inputs, and these prices reflect both the scarcity of the inputs and their value in other uses. If the input prices are assumed to be constant, the relative prices of K and L can be shown by a straight line. The position of the line relative to the axes reflects the total money available; and the slope shows the ratio of prices which in Figure F-1 is the ratio of the price of labor to the price of capital. For a given ratio of input prices, the lowest cost combination of inputs can be determined by the point of tangency of the relative-price line with the equal-output curve. In Figure F-1, this is point A, which will take L_A units of labor and K_A units of capital at a total cost of M. $\bar{Y}$ can also be produced for more than M by using other combinations of K and L, but it cannot be produced for less, given the prices P_K and P_L for capital and labor. Therefore, point A shows the most efficient way of producing the desired output for the existing relative prices.

Although profit in a simple two-input model is usually thought of as included in the price of capital, it may be useful (in order to make the above discussion compatible with the weighted-profits method) to think of an additional return, say to the person providing funds during the production process. Thus, if the cost M for producing $\bar{Y}$ is less than the price offered for $\bar{Y}$, there will be a return to these funds. This profit is maximized by producing at the lowest cost (point A in Figure F-1), because the price offered is independent of the method of production.

Incentives provided by the ASPR weighted-profit factors (Table F, above), however, distort the cost-minimization process. The government is not indifferent to the way the constant output $\bar{Y}$ is produced but is willing to pay a price that includes a higher profit rate when a certain input is used. The differential profit factor weights, say 5 percent of the cost of K and 9 percent of the cost of L, change the relative prices of K and L. The market prices of K and L remain unchanged, but the use of L gives a 4-percent additional profit and L becomes relatively more profitable. Thus, in Figure F-2 there are two important ratios between capital and labor. The line VV' tangent to the equal-output curve at point A is based on the market prices and shows what must be paid to the inputs. Any point along this line corresponds to a constant input cost of M, but $\bar{Y}$ can be obtained for this cost only if the combination of inputs at point A is used. In terms of the contribution to profits, however, a new relative price line WW' comes in. Now the intercept on the capital axis is (1.05) M/P_K, rather than

M/F_K, and the intercept on the labor axis is (1.09) M/P_L. Here (1.05)M would be the price including the profit if only K were used in the production process; and (1.09)M would be the price if only L were used in production. Since the line WW' shows the costs plus profits, the combination of inputs to produce $\overline{Y}$ must still be determined.

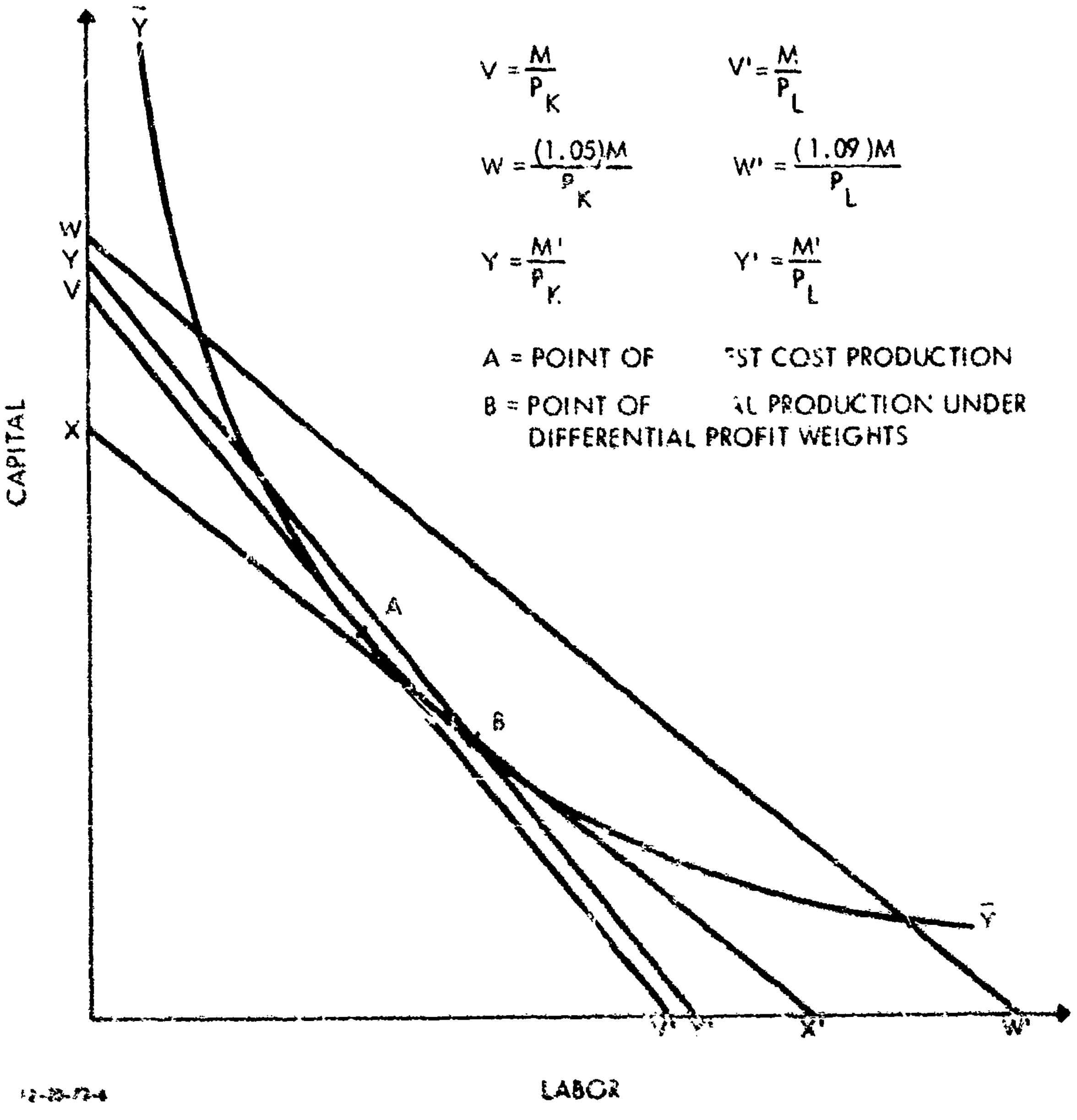


Figure F-2. CHOICE OF INEFFICIENT PRODUCTION METHOD

If production decisions are made on the basis of profits, the inputs will be chosen on the basis of their differential contributions to profit, as well as on the basis of their market prices. The lowest-cost production point using these two criteria of price and profit contribution is point B, which is the point of tangency between $\bar{Y}$ and the line XX', which, being parallel to WW', shows the same contributions to profits. But producing by method B will cost more than the M by method A for the same input prices of P_K and P_L. This increase in the budget constraint to M can be shown by a line YY' that passes through point B (to enable production by this method) and has the same slope as VV' (to show the same relative prices of the inputs). Thus, when inputs have differential contributions to profits, the combination of inputs chosen is less efficient and costs more than the most efficient method. Although the most efficient method was described earlier as resulting when the price offered is independent of the costs, an equal-percentage profit contribution for all inputs would also induce the most efficient production method.

So far the increased resource cost for using method B rather than A has been discussed. The government, however, is concerned with the price including profit that it must pay. For the given profit weights, the government pays a higher price for goods produced by input-combination B rather than by the efficient combination A. This is both because more of the more heavily weighted input is used at B (increasing the profits) and because the costs on which the profits are based are higher at B.

An even more expensive way of producing $\bar{Y}$ than by method B could have been chosen, which would have used more of the heavily weighted input. But if there is enough competition from other potential producers even when negotiated prices are required, the most efficient (lowest cost) method, for the given incentives, will tend to be chosen.

3. Theory Summarized

To sum up the above necessarily theoretical discussion, the weighted profit-guidelines of ASPR tend to induce more expensive methods of production and higher procurement costs. These higher costs result from the allowance of differential profit rates depending on the type of input used. Because market prices of inputs already reflect their scarcity and value in other uses, production decisions should be based on the relative prices of the inputs. But firms are assumed to maximize profits and so base their decisions on the contributions of the inputs to profits. When profits depend on the type of input used as well as on the costs, the choice of inputs for production of the desired output is biased toward the use of the inputs with the higher profit weights. This bias or distortion increases the production costs above the minimum (efficient) costs of production. In addition to the increase in production costs, the price, including profit, paid by the government is increased. The increase in price is due both to the use of inputs with the higher profit weights and to the higher overall production costs that profits are based on.

The above theoretical analysis shows that if the procurement procedure is a negotiated, sole-source contract, the ASPR profit-factor weights will lead to a combination of inputs that represents an input cost in excess of the minimum necessary to produce the same level of output. This will be true even when there exists a competition for selection of supplies. Before examining how this result might become an important factor in determining the winner of a reprocurement award under competitive bidding, it is necessary to explore the relationship between the unit price charged and the underlying cost structure within the context of a negatively sloped progress curve.

4. Empirical Indications

In spite of this extensive theoretical discussion of the ASPR profit guidelines, it is difficult to show conclusively that production methods are not efficient and that some costs are excessively high. And because this appendix has argued that particular costs (those with high profit weights) are inflated over the general tendency of cost justification, some evidence of the excessive use of labor is needed. This empirical work was not done, because of the emphasis of the project on other aspects of competition, but there is some tentative evidence provided by other studies. For example, the work by Peck and Scherer [63], *The Weapons Acquisition Process: An Economic Analysis*, reported on a study of the productivity of engineers in the weapons industry:

> The study concluded that improved utilization of scientific and engineering manpower would give increased output yields of up to 100 times, the most likely potential increase being estimated at 10 times. Reasons for the low indicated productivity included the use of engineers on routine jobs, assignments of little or no value, unnecessary duplication of effort, high turnover (the average survey respondent changed jobs every 3.3 years), and effort spent on unassigned projects. The authors cited as underlying causes of these problems the difficulty of keeping informed on technical advances, government duplication of projects, design competitions, duplication by prime contractors of subcontractors' work, *the mass engineering philosophy inspired by operation under cost reimbursement contracts*, and inadequate management. [63, pp. 515-516; emphasis added]

A recent study by the Logistics Management Institute (LMI) also reported some empirical evidence that "cost-based pricing leads to excessive labor and higher costs" [64, p. 18; see also pp. 18-22]. In addition to these perverse incentives from prices based on costs, LMI also reported on the common industry view that the work will be spread among the firms in an industry; this view encourages overbuilding and overstaffing in order to get future work [64, pp. 15-16].

Thus, the empirical evidence from other studies shows that the cost-based profit guidelines of ASPR have an impact on increasing costs. This impact, however, is only one aspect of several overall incentives within government procurement practices to increase costs. Nevertheless, the bias induced by the differential ASPR profit weights has been neglected in previous discussions of incentives, and this appendix has tried to remedy the neglect.

B. PRICING POLICIES AND EFFECTIVE COMPETITION

1. Pricing Policies Under ASPR

A potential source of confusion throughout the analysis of the effects of competitive procurements is the relationship between the prices charged and the production costs. For negotiated and sole-source procurements, some form of price or cost analysis is required by ASPR; and when the weighted profit guidelines are used, there is a strong relationship between costs and prices, because prices are costs plus the profit objective. Therefore, when manufacturing costs follow a negatively sloped progress curve, prices of subsequent units will fall as well. When procurements are formally advertised, however, DoD is not required to take into account the costs and profits, since contracts must be firm fixed-price or fixed-price with escalation [ASPR 2-104.1]. Thus, with procurement by formal advertising, there is no indication that prices closely follow costs; the relationship will depend on the pricing policy used. There is also the general presumption that price competition is adequate in formally advertised procurement [see the conditions listed in ASPR 3-807.1(b) (1)a], so the following analysis will assume that commercial, competitive pricing policies are followed under formally advertised procurements.

2. Description of Commercial and Negotiated Pricing Policies

The usual description of commercial (assumed competitive) pricing policy is a constant price for a large fixed number of units. So in Figure F-3, if production costs follow a progress curve L, the loss in area A for the early units (due to the constant price) is offset by the profit in area B on the later, lower-cost units of output. To a certain extent, this pricing policy is followed in negotiated defense procurements, since on each buy a total price and an output are set, giving a constant average price per unit. The important difference between commercial and defense pricing practice appears to be in how the quantities are set. In the commercial case, the quantity (Q_C in Figure F-3) on which a profit is to be made is determined by the expected sales over an extended period of time. In defense procurement, however, there is often a series of buys, but if the current producer can assume with some reliability in a sole-source case that he will get the subsequent procurements, the expected output is larger than called for by the initial contract. Assume in Figure F-3 that Q_D is the total expected output for the series of negotiated procurements. If the first contract is for a total output of Q_1, the defense pricing policy will set a price P_1 that will yield a reasonable rate of return on the costs of that contract. On the next contracts $(Q_2 - Q_1)$ and $(Q_D - Q_2)$, average prices P_2 and P_3 are set that earn a similar profit rate on the associated costs. Thus, with this kind of pricing procedure, there is a closer relationship between prices and costs than in the commercial case described to the left in Figure F-3. In both cases, however, a similar overall profit rate may be earned.

3. Effective Competition Only on First Buy

The relationship between prices and costs is important in maintaining effective competition in a series of procurements.

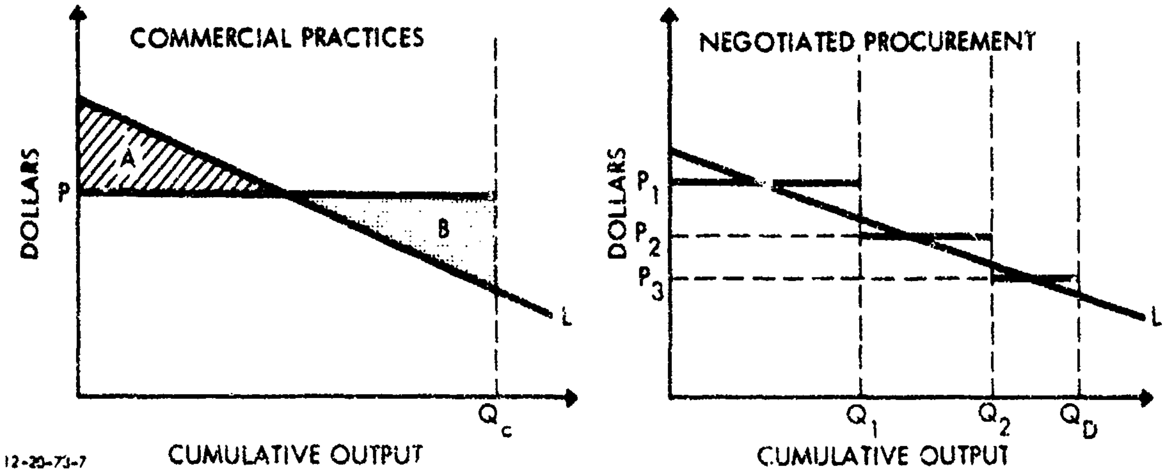


Figure F-3. PRICING POLICIES

The maintenance of effective competition when production costs are falling as cumulative output increases depends on the size and number of competitive buys. In a competitive, formally advertised procurement for a fixed quantity, as long as all firms have similar costs, each firm will bid a price allowing the lowest acceptable profit or a competitive rate of return. However, if one firm has initial costs much lower than the other firms, it can underbid the others and still get a greater-than-competitive profit. Here, competition is not effective in eliminating excess profit. But if this situation is recognized by the procurement officer, there is no longer adequate price competition according to ASPR [3-807.1(b)(1)b], and there would have to be negotiation of prices rather than formally advertised procurement. Since the low-cost firm may retain strong bargaining power, high profits may remain even with negotiation. ASPR does recognize the difficulty of eliminating all excess profits and states:

> While the public interest requires that excessive profits be avoided, the contracting officer should not become so preoccupied with particular elements of a contractor's estimate of cost and profit that

> the most important consideration, the total price itself, is distorted or diminished in its significance. [ASPR 3-806(b)]

Thus, with initially similar costs, effective competition can be obtained on the first contract and there will be no excess profits. But when a subsequent contract is considered, there is the question of how many competitors there will be. If all firms faced the same potential progress curve for costs at the first buy, and if one firm won all (or even the largest part) of the first contract, then this firm would have a cost advantage on the later buy because it is farther down its progress curve. This firm can slightly underbid its competitors, win the second contract, and earn more than a competitive profit.

This process can be seen in Figure F-4, where L is the progress curve faced by all firms, Q_1 is the amount of the first competitive buy, and $(Q_2 - Q_1)$ is the amount of the second buy. If price P_1 is the average price per unit on the first buy that just yields a competitive rate of return on the costs of the first buy, then for an additional equal buy of Q_1 $(= Q_2 - Q_1)$ the nonproducing firms will charge P_1 again to get a competitive return on their costs. (Of course, the second buy does not have to be the same size as the first; but equal size is assumed, to simplify the diagrams and reduce the number of prices to be considered.) The firm winning the first contract, however, will have to cover lower costs, shown by the area under curve L between Q_1 and Q_2. Assume that an average price of P_2 will give a competitive return on the latter costs. The current producer can therefore charge some price P_M between P_2 and P_1 such that its nonproducing competitors are just underbid. The excess profits are then measured by $(P_M - P_2)(Q_2 - Q_1)$. It may look as if there are two competitive procurements in this example; but when one firm gets all the first bid and when the firms initially face similar costs, the winning firm has a cost advantage on the later buys--allowing it a greater than competitive profit and eliminating effective competition.

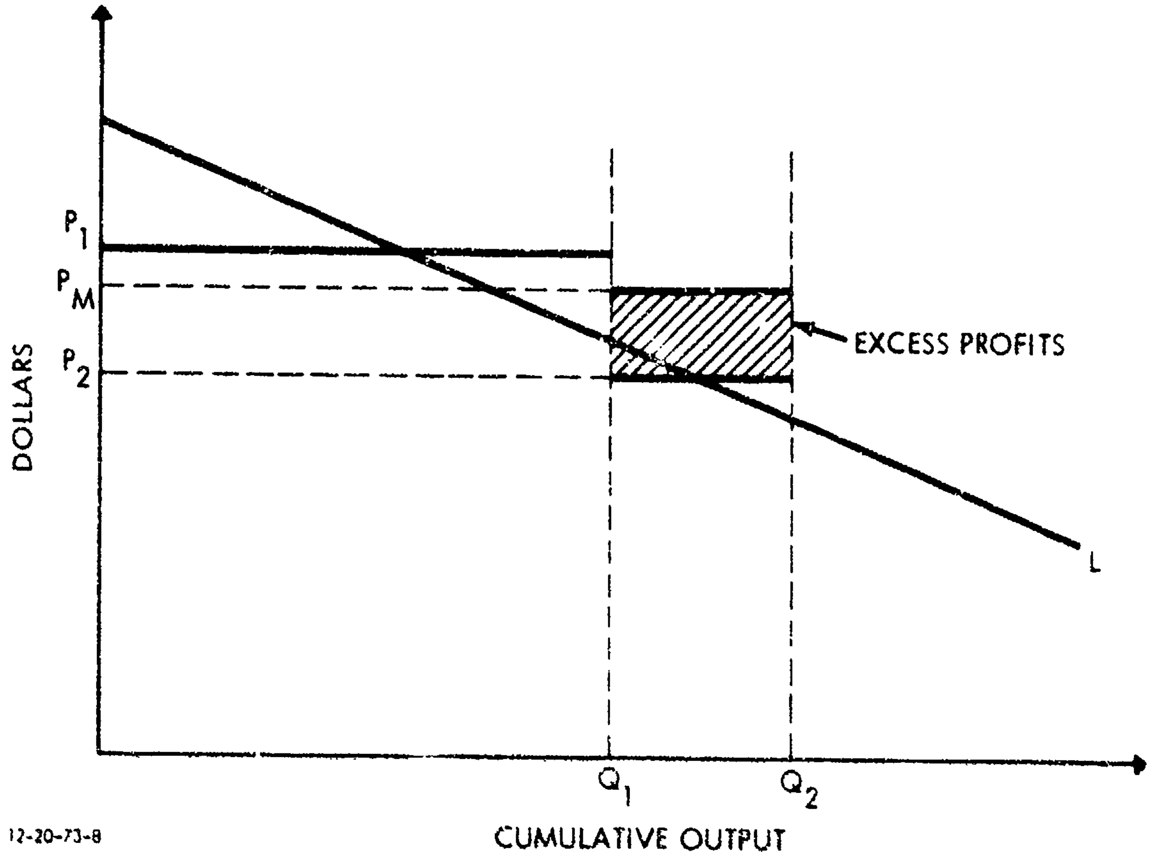


Figure F-4. INEFFECTIVE COMPETITION ON SECOND BUY

4. Effective Competition Over Series of Buys

Still assuming that costs of all firms are initially similar and that any change in costs can be predicted and obtained by all of them, effective competition over the total desired output can be maintained even in the presence of progress curves. It can be maintained by eliminating the cost advantage that the contract winner has on later buys. Before discussing several ways in which competition can be maintained, it should be pointed out that the suggestions are based on the assumption that the producing firm has a cost advantage. However, if non-producers can also lower their costs (e.g., through unpredicted technological changes or by not licensing the current producer to use a certain patent), then effective competition can be had on more than the first buy; and large procurements will not be desirable. Thus, the recommendations of this section would apply more to standardized products with a slowly changing technology base than to products in a rapidly changing field.

One obvious way to eliminate the cost advantage of the contract winner is by splitting the output evenly over all firms with fairly close bids (still assuming that the initial costs of all firms are similar). This splitting means, however, that the total production costs (and so prices) will be higher than in a winner-take-all bidding, simply because costs are assumed to fall as cumulative output increases. Since giving bidders equal shares of the total procurement will maintain effective competition over a series of buys, profits are not excessive--but at the cost of excessively high production costs.

Another way of maintaining effective competition is to consolidate the series of procurements into one competition. This method is designed to lower the production costs by having the contracts on a winner-take-all basis, and it will be shown that excess profits will be eliminated as well. Consolidation of the series of buys can be done in two ways: (1) requesting bids on a winner-take-all basis for Q_2 (in Figure F-5), or (2) requesting bids for Q_1 with the statement that an additional quantity ($Q_2 - Q_1$) will be bought in the future. If the competitive bid is for quantity Q_2, then an average price of P_3 will be bid, where P_3 will just give a competitive rate of return over costs of the whole quantity. (P_3 is between prices P_1 and P_2, which as defined earlier for Figure F-4 just allow competitive returns on the quantities Q_1 and ($Q_2 - Q_1$), respectively.)

If, however, the competitive bid is for quantity Q_1 with an announced separate procurement of ($Q_2 - Q_1$) later, where again for simplicity the two procurements are the same size,

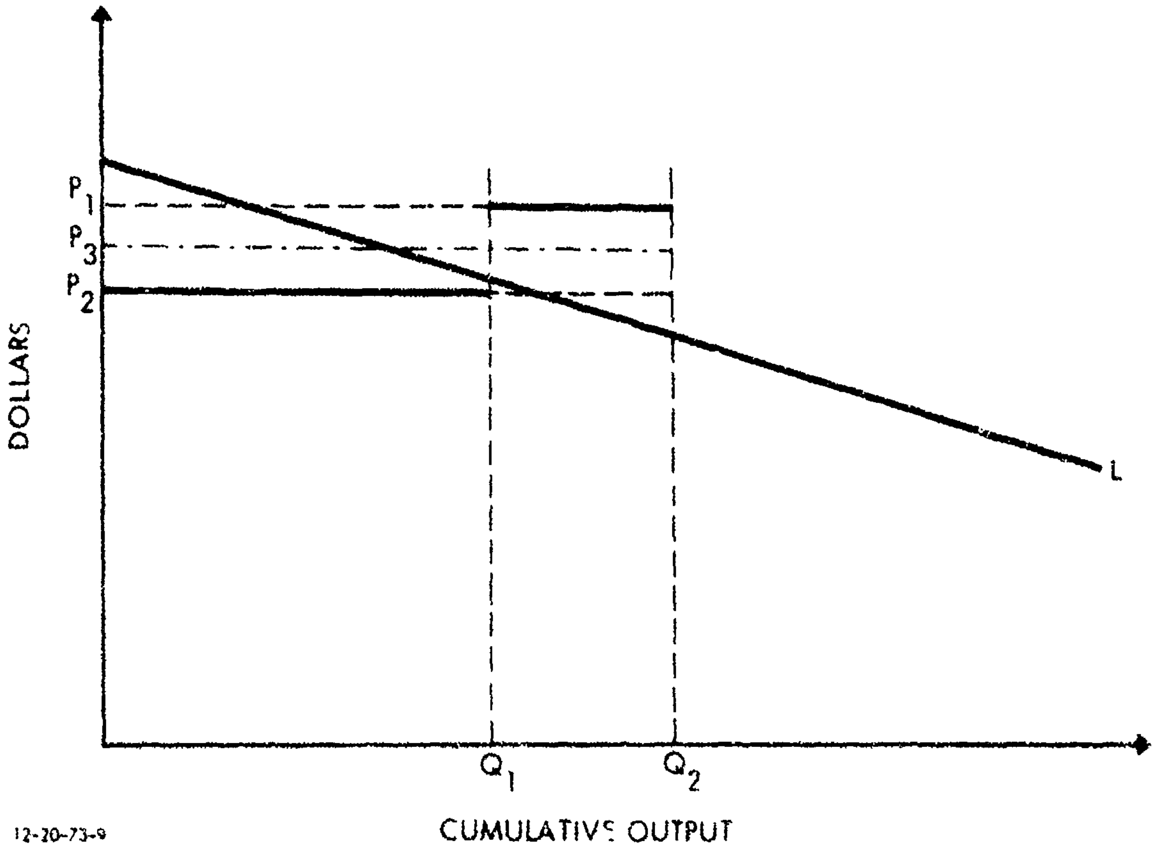


Figure F-5. PRICING POLICIES UNDER EFFECTIVE COMPETITION

the bidders know that the winner of the first competition will have a cost advantage on the second buy and will win it as well. On the second equal-sized buy the nonproducing firms (the losers on the first competition) will bid P_1 to give a competitive return on their higher costs, so this is the maximum that the winner of the first competition can bid on the second buy. To get an overall competitive return, assuming that slightly less than P_1 will be charged on the second buy, a price slightly more than P_2 will be bid on the first buy. The competitive bidding will reverse the prices, giving competitive returns--the price P_2 on the first bid gives a competitive return on the costs of the second quantity, while the price P_1 on the second bid gives a competitive return on the costs of the first. Although this reversal of the prices bid may appear to be unduly complicated and to break unnecessarily the tie between costs and prices, this price pattern is generated by competitive bidding because of the cost advantage of the winning firm on the second procurement. If there are other factors involved (e.g., the bidders feel constrained not to raise the price on the second procurement and even to lower price somewhat), a different pattern of prices will result, such as the constant price P_3 over the whole output, where P_3 had been defined to give a competitive return on the overall costs.

5. Theory Summarized

The basic points of this section are that (1) the presence of progress curves generally gives lowest costs when production is by a single firm, (2) actual production experience gives a cost advantage over nonproducing firms, and (3) effective competition requires costs to be fairly close. Therefore, to have the lowest production costs and to minimize excessive profits to the contractors, DoD must choose a single producer but ensure that its entire purchase is effectively competed, with all bidders facing similar costs. This can be done either by obtaining bids at one time for the total output to be procured or by purchasing a series of smaller quantities with an initial announcement of the total procurement. Effective competition is not maintained with a series of unconnected winner-take-all competitions, because the winner of the first will have a cost advantage in the later competitions, though this advantage will not be reflected in the first price bid.

This discussion has also shown that the pricing policies under competition can have little direct relationship to the actual costs of production. Over the relevant decision-quantity, a competitive return will be earned. But as Figure F-5 has shown, the price on one contract may be more appropriate to the costs of another contract than to its own production costs. The lack of relationship between prices and unit (rather than total) costs means that the distinction between prices and costs is particularly important. Progress curves depicting production costs cannot then be easily derived from price data for competitive firm fixed-price contracts. Moreover, comparisons of pre- and post-competitive progress curves from price data must be carefully qualified and restricted. Nevertheless, procurement decisions made on the basis of the total costs (rather than unit costs) for the total desired quantity will still be correct.

C. SOLE-SOURCE VERSUS COMPETITIVE PROGRESS CURVES AND PRICE-QUANTITY RELATIONSHIPS

To complete this discussion, we need to examine two distinct questions: (1) whether negotiated or competitive contracts imply fundamentally different underlying cost progress curves, and (2) whether as a consequence of pricing practices in successive competitive procurements what is empirically observed is not the true cost progress curve but a competitive price-quantity curve. In what follows we will show (1) that there are sound theoretical reasons to support the existence of a price-quantity curve in the competitive case that is flatter than in the sole-source case (which would explain the observed result of a shift in suppliers at the time of first reprocurement under competitive conditions), and (2) that pricing practices used in subsequent competitive procurements will lead to the empirical observation of a competitive price curve even flatter than the competitive-cost progress curve. These questions will be treated in the order they were raised.

1. Definition of Efficient Production

The argument[1] leading to the conclusion that the initial supplier has a distinct cost advantage over all potential

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[1] See Figure F-4, above.

competitors on subsequent buys, permitting him to extract excess profits, hinges on some special conditions. It was explicitly assumed that all producers had the same (or at least very similar) production costs--specifically by the statement that all firms faced the same progress curve. In addition, and of crucial importance, an implicit assumption was made that the common underlying production process was in fact the most efficient one available, where efficiency is defined to mean the employment of the respective factors of production in such a mixture as to yield any given output at the least possible cost. As defined, a relative judgment of efficiency is made by simultaneously considering the contribution to productivity of any particular factor and its cost. Section A of this appendix showed that the ASPR weights might encourage inefficient production; we want to examine here the resulting outcome stemming from the use of an inefficient mode.[1]

In a negotiated contract for any particular piece of equipment, the supplier must develop rather precise estimates regarding the quantity and quality of inputs to be used in production (e.g., so many man-hours of engineering labor, so many man-hours of production labor, etc.). These estimates then form the basis for his production cost and, most importantly, become an integral part of the procurement contract. This contractual relationship also fixes the production process in the sense of prescribing the mix of inputs that will be used in producing the equipment in question. Once the input proportions are fixed, the associated progress curve is also fixed, since the progress curve is peculiar to the choice of inputs as well as to the type of equipment being produced. Though

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[1] To concentrate the focus of the inquiry, we will set aside some important questions such as proprietary patents, inventions and methodologies, or, in general, those things that may give a distinct technical advantage to a subset of producers.

sensitive to a complex set of elements, the downward-sloping progress curve involves a learning phenomenon where an increase in physical productivity is derived from performing the same function over and over again. Any input will have embedded within it a magnitude of latent learning-potential, ranging say from zero for a simple machine to some large value for an intelligent but not specially trained human input. The degree of realization of this latent potential will depend on the peculiarities of the output involved. A complex assembly made in turn from complex subassemblies, each with several components, allows room for a great deal of learned efficiency of technique, while a simple assembly with indelicate and trivial subassemblies does not. Thus, an interaction operates between the inputs and output and the learning phenomenon, but once the input mix and output type are fixed so is the structure of the progress curve.

2. Sole-Source Progress Curve

If we assume that the input mix agreed to in the negotiated procurement contract is not the most efficient mix possible, then the contractual progress curve would lie above the progress curve that would have prevailed under the case of the most efficient mix. How far above depends on the initial difference in productivity between the two production schemes (contractual and most efficient) and the rate at which learning takes place within the respective schemes as cumulative output increases (i.e., the slopes of the respective progress curves). The slope of the progress curve associated with the inefficient production scheme may be steeper than, the same as, or less steep than the slope associated with the efficient scheme, but (by definition of efficiency) this progress curve must lie everywhere above the progress curve of the efficient scheme.

If we superimpose the necessarily higher intercept value and the observed steeper slope of the progress curve for the inefficient scheme, we would produce the situation shown in Figure F-6, where L' and L are the inefficient and efficient progress curves, respectively.

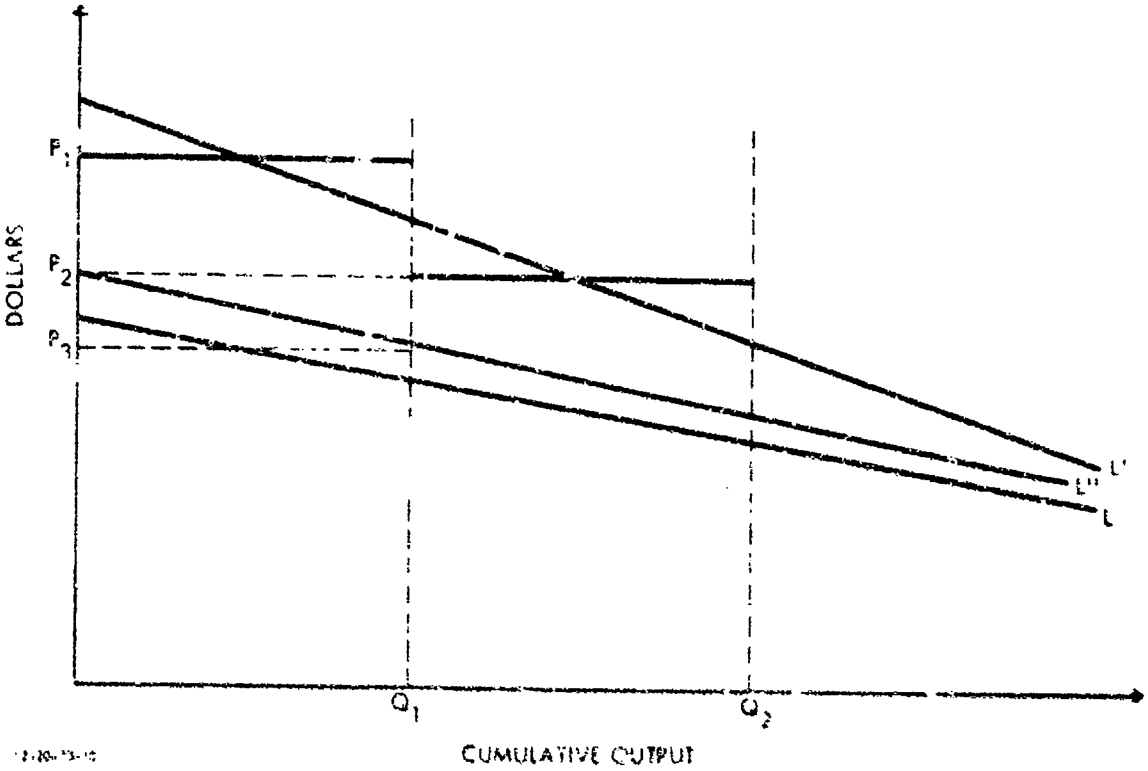

Figure F-6. PLOT OF EFFICIENT AND INEFFICIENT PROGRESS CURVES

Now suppose a negotiated contract is awarded for the quantity of output shown by Q_1 to a supplier with progress curve L'. With no loss of generality, we can assume that L and L' already embody an ordinary return over actual outlay. Then the unit price that would prevail for this procurement would be P_1, following the argument developed earlier (in the discussion of Figure F-4, above), and full costs would just be covered. On a subsequent purchase of equal size ($[Q_2 - Q_1] = Q_1$), the inefficient firm would just cover its cost and earn an ordinary return by charging price [illegible]. But if the second purchase was made after open price-competition, the firm with progress curve L could bid a price P_3 and win the competition, still earning an ordinary return.

If Figure F-6, then, correctly portrays the underlying progress curves, it is not inconsistent to observe the result in price-competitive successive buys of the original supplier's losing the procurement contract. A close examination of Figure F-6 will reveal that it is not permissible to make a statement stronger than that such a shifting of suppliers is possible. Shifting of suppliers is by no means necessary; and, given a different relative structure of the progress curves or different-sized procurements, there need be no shift. Consider, for example, changing the relative position of L' and L in Figure F-6 so that the intercept value of L' is only slightly above that of L, keeping the procurements at sizes Q_1 and Q_2, respectively (as shown by L" in Figure F-6). If we were to show the prices that would prevail using L", then on a competitive second buy the inefficient producer would again win the contract.

3. Relative Slopes of the Two Progress Curves

To complete this discussion, we need to provide a theoretical rationale for drawing the curve L' in Figure F-6 with a steeper slope than the curve L--in other words, the reason that the slope of the progress curve of the inefficient production scheme should be steeper than that of the efficient. To accomplish this, we need to explore further what is meant by "efficiency." By definition, efficient production means lowest cost for any given level of output. Functionally, efficient production means to choose that mix of factors of production (labor and capital) which minimizes cost for any given level of output. An efficient production scheme, then, would produce the optimal progress curve and, as well, the least cost for any output.

Within the context of a negotiated procurement situation, where the profit rate is governed by the ASPR guidelines, cost justification becomes more important than cost minimization. Also, as shown by Table F, the ASPR guidelines are heavily weighted in favor of extensive use of labor--especially engineering labor. One consequence of the guidelines is that a potential supplier with a large complement of research-and-development (R&D) personnel (a very important aspect in winning a design competition) will attempt to retain these inputs as part of his production costs. Another consequence is that he will substitute production labor for capital. Both these acts, the loading of R&D personnel onto his production scheme and the substitution of production labor for capital, will be to the economic advantage of the supplier; and he will engage in them up to the limit to which he is able to justify his costs and not jeopardize his chances of winning a contract.

But such a procedure is a distortion of the mix of factors of production away from the optimal specified above (Subsection 1), and this distortion will produce higher unit costs for all levels of output. Moreover, the substitution of labor for capital (while being more expensive) will produce a higher rate of learning than takes place in the efficient production scheme, following from the fact that the learning process associates more directly with labor than with capital. The combination of higher unit costs and a higher rate of learning will produce a progress curve in the inefficient production scheme with a larger intercept value and a steeper slope than the progress curve for the efficient scheme.

4. Observed Price-Quantity Curves

In all cases where the second and subsequent procurements are made under competitive conditions, the fixed-price contract does not permit direct observation of a cost-quantity relationship. What is observed at the first and subsequent competitive procurements is the quantity purchased and the purchase price. If the price specified in the winning bid was just that price which covers cost (including an ordinary return), given the number of units bought, then the curve empirically estimated from the data would be the legitimate cost-quantity relationship; however, there is theoretical evidence to show that the estimated curve may deviate from this.

In Figure F-7 (below), let L represent the true optimal progress curve and Q_1 and Q_2 the quantities of the first and second competitive procurements--a sole-source procurement of a given size has already preceded these. The successful bidder in the first competitive procurement wins the competition by bidding a price P_1, which just covers his cost of producing the cumulative output Q_1. Following this, let there be a subsequent competitive procurement of size Q_2, also won by the supplier of Q_1. If the second bid is based solely on cost, a price P_2 would prevail. These two procurements, then, would produce observations of the two ordered pairs (P_1, Q_1) and (P_2, Q_2), from which we could, by adjusting our quantity data to the midpoints of the two procurements (points a and b in Figure F-7), estimate the line L, the true cost or progress curve.

However, by assumption, the winner of the first competitive procurement is the most efficient producer and he need not bid a price as low as P_2 to win the second competitive procurement; any price less than P_1 will be sufficient to win. Consider that he bids a price $P_M > P_2$. [illegible]t we will observe empirically in this case are the ordered pairs (P_1, Q_1) and (P_M, Q_2), and our estimated relationship will now be fit to the points a and b' (shown as L* in Figure F-7). The curve L* has a lower intercept and less steep slope than the curve L.

A further possibility, which would produce an even flatter curve than the observed curve L*, would be the case where one

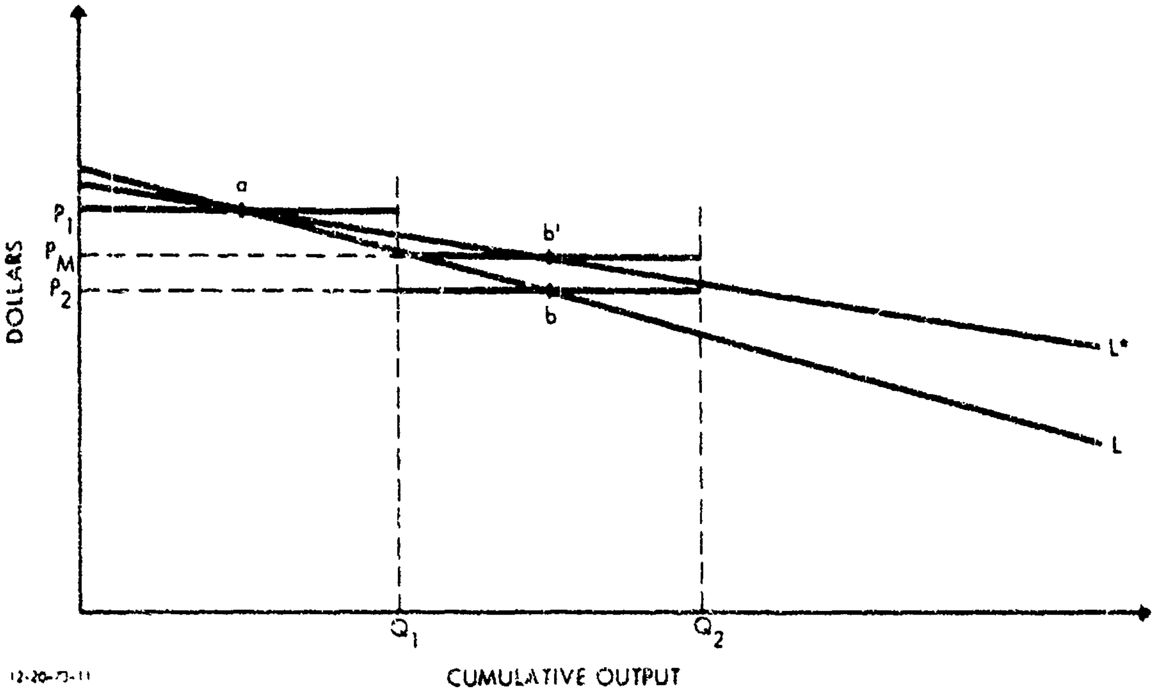

Figure F-7. PRICE-QUANTITY VERSUS COST-QUANTITY

supplier wanted to win the first competition badly enough to bid below his cost on the first procurement. Such an action would make our first observed value some number a' < a, which, combined with b', would produce a curve with a lower intercept-value and flatter slope than for L*. Bidding below cost on the first procurement is not necessarily irrational behavior as a market strategy. The cost advantage the initial supplier has over all others on the second and subsequent procurements, and the potential for excess profits, makes winning the first competition very important. He is, however, confronted by the uncertain event of there ever being subsequent procurements.

APPENDIX G

SOURCES CONTACTED FOR COMPETITIVE DATA BASE

Appendix G

SOURCES CONTACTED FOR COMPETITIVE DATA BASE

Early in the study it was decided that the analysis of the effect of competition on the acquisition prices of equipment would be based on the procurement histories of items that the services had purchased under both sole-source and competitive type contracts. It was expected that there would not be too much difficulty in obtaining a comprehensive list of equipment with such procurement histories and that the main problem would be in obtaining the year-by-year cost-quantity data. The expectation was correct in that the detailed procurement histories of candidate items were not easily obtained, but the surprise was that there did not seem to be any way to develop a comprehensive list that showed all the equipment that had been procured under both sole-source and competitive contracts.

An early lead that promised to provide a comprehensive list of the desired procurements was the file of data from the *Individual Procurement Action Report* (DD Form 350), which is made out by the contracting officers of all services for all procurements of over $10,000 value. These data are kept in a computer file in the Pentagon and include information on the extent of competition in the contracts. Unfortunately, the file could not be searched for procurements of specific equipments; it was possible to--and we did--determine the sole-source and competitive procurements by year for Federal Stock Classes (FCS) within a Weapon System Code, but there was no way to identify the specific items within the FCS.

Another source that seemed promising was the automated Procurement Record Histories of the Army and the Air Force. The individual commodity commands of the Army and the Air Material Areas (AMA) of the Air Force Logistics Command (AFLC) record a great deal of data in a computer file about each procurement contract they make. Among other things, these files identify items by name and Federal Stock Number (FSN) and give the date, number of items, unit price, and type of negotiation for each contract. If the files were complete, they would be capable of providing exactly the data required. Before requesting this information from the Army and the Air Force, however, a check was made at two of the AMAs and the Army Electronics Command to see if the information in the files was really adequate. It was not. The Procurement Record History file data was characterized by internal inconsistency and incompleteness. Many known procurements were simply not entered into the file. At any event, the data in them did not seem to be worth the considerable effort that would be required in having the AMAs and the Army commodity commands prepare the special programs necessary to search the files for our needs.

After determining that there was no mechanical way to develop a truly comprehensive list of procurements meeting the desired criteria, it was decided to solicit the information from as many potential sources as could be determined. The random nature of the sample was preserved by asking the personnel contacted for the names of all equipment they knew of that had been procured under both sole-source and competitive contracts. In general, the effort involved (1) following up leads found from the literature search and (2) personally contacting procurement and project offices in the commands of the three services. In addition to asking the individuals in these offices for the names of items of equipment, they were also asked if they knew of other possible sources of the data we needed; and then these leads were followed.

After obtaining the name of an item that had the desired contractual history, it was necessary to find the specific year-by-year details essential for the progress-curve analysis. For only a minority of the candidate items found was it possible to obtain usable data. The information either was not available or was incomplete, or engineering changes had distorted the price data too much for it to be used. An example of this problem is the M-113 Armored Personnel Carrier, which was cited as a good candidate system since there had been 23 separate procurements of the vehicle over a 12-year period by both sole-source and competitive contracts. Further investigation, however, revealed that most of the records were in dead storage and that there had been almost continuous major engineering changes over the life of the equipment. The track system had been greatly altered, the engine had changed from gas to diesel, the transmission which had been contractor-furnished equipment (CFE) during the early years of the procurement had later become government-furnished equipment (GFE), and there were many other changes--all of which impacted directly on the unit price of the vehicle. To have obtained all the necessary records and then to have calculated the effect on costs of the engineering changes so that the influence of competition on the unit price could be estimated would have been a major study in itself.

In Appendix H, there are summaries of the data that were collected on all the equipment that were used in developing the estimating relationship for the effect of competition. Summaries of the cost histories for some of the equipment that was not used in the analysis are also included, for general information.

Inasmuch as no mechanical way was discovered to develop a list of equipment meeting our criteria, and since the actual list finally used is small, it seems appropriate to list the agencies contacted in the data search. Many of these agencies were visited and a number of individuals in several offices were contacted; others were limited to telephone discussions. In all cases, however, the persons in the agencies were asked whether they knew of any mechanical way to generate the list we desired and if they would tell us the names of any specific equipment that they thought might meet our criteria. The principal agencies contacted are listed below:

Defense Contract Audit Agency
Office of the Secretary of Defense
  - DDPA&E Cost Analysis Division
  - ASD (Comptroller), DAS (Systems Policy and Information)
  - ASD(I&L), DAS (Procurement)

U.S. Army Hq., Director of Materiel Acquisition
U.S.A. Aviations Systems Command
  - Procurement Division
  - Comptroller, Cost Analysis Division

U.S.A. Mobility Equipment Command
  - Production and Procurement Directorate
  - Comptroller, Cost Analysis Division

U.S.A. Tank-Automotive Command, Production and Procurement Directorate
U.S.A. Weapons Command, Production and Procurement Directorate
U.S.A. Missile Command
  - Production and Procurement Directorate
  - Comptroller, Contract Cost Division

U.S.A. Electronics Command
  - Comptroller, Cost Analysis Division (Ft. Monmouth)
  - Production and Procurement Directorate (Philadelphia)

U.S.A. Materiel Command
  - Production and Procurement Directorate
  - Comptroller, Cost Analysis Division
  - Spare Parts Program Manager

U.S.A. Logistics Management Center
  - Defense Logistics Study Group
  - School of Acquisition Management

Hq. U.S. Navy
  - Comptroller
    - Director of Budget and Reports
    - Assistant for Cost Review and Analysis
  - Management Information Office
  - Program Planning Office, Systems Analysis Division

U.S.N. Material Command, DCNM Procurement and Production

U.S.N. Air Systems Command
- Project Manager Offices for A6A, Anti-Radiation Missiles (SHRIKE, STANDARD ARM), SIDEWINDER
- Aircraft Components Purchase Division
- Weapons Systems Purchase Division
- Asst. Commander for Material Acquisition
    - Acquisition Control and Resources Division
    - Air-Launched Missiles Branch
    - Air-to-Air Guided Missile Branch
    - Air-to-Surface Guided Missile Branch

U.S.N. Ordnance Systems Command
- Torpedo MK-48 Weapon System Project Office
- Surface Missile Systems Project Office

U.S.N. Ship Systems Command, Naval Ship Engineering Center

Hq. U.S. Air Force
- Comptroller
    - Directorate of Data Automation
    - Directorate of Management Analysis
    - Directorate of Procurement Policy

Hq. Air Force Systems Command
- Cost Estimating and Analysis Division
- Cost Information and Management Support Division
- Director of Procurement

AFSC, Aeronautical Systems Division
- Director of Procurement and Production
- Comptroller, Cost Analysis Division
- Deputy for Reconnaissance and Electronic Warfare
- Deputy for Systems Management
- Deputy for Subsystems Management

AFSC, Electronics Systems Division, Cost Analysis Branch

Hq. Air Force Logistics Command
- Director of Procurement
- Sacramento Air Material Area
- Ogden Air Material Area
- Warner Robbins Air Material Area

Space and Missile Organization, Cost Analysis Division

APPENDIX H

DETAILS OF THE DATA COLLECTED FOR THE ANALYSIS OF THE EFFECT OF COMPETITION ON PRICE

CONTENTS

Appendix H

DETAILS OF THE DATA COLLECTED FOR THE ANALYSIS OF THE EFFECT OF COMPETITION ON PRICE

A. GENERAL

In order to make a quantitative evaluation of the effect of competition on price, it was necessary to obtain data that could be normalized to isolate the effect of competition on price changes from the many other factors that affect them. The kind of data that seemed most likely to permit this was procurement histories of items that had been purchased under both sole-source and competitive contracts. The progress curves from a large number of such histories might reveal discontinuities at the points where competition was introduced that would permit quantitative analysis of the effect of competition, if, indeed, there was any pattern on how competition affected prices. Naturally, due consideration would have to be given to other factors that impacted on the prices, such as urgency of the requirement, engineering changes, time breaks in production, etc.

As mentioned in the body of the report, the collection of these procurement histories proved to be more difficult than anticipated; for example, a comprehensive list of the names of items with a unit value exceeding $1,000 which had been procured under both sole-source and competitive contracts could not be developed. It seems useful, therefore, to display in this report the data that was collected--even that data which could not be used in the quantitative analysis. In relation to the time and effort spent on the collection effort, the actual quantity of data obtained seems small. However, this is the sort of information that is essential to a quantitative examination of the effect of competition on costs, and it should be of value both to persons reviewing the methodology used in this study and to those doing subsequent analysis in this area. Therefore, even at the cost of adding considerably to the bulk of the report, the data base is presented here in considerable detail.

The information displayed here falls into three categories: (1) that which was used in the quantitative analysis, (2) that which was dropped from the quantitative data base after careful study, and (3) that which was obviously not suitable for the analysis. The data will be discussed in the order of those three categories. Prices are tabulated in constant 1970 dollars. Escalation tables obtained from the Office of the Secretary of Defense (OSD) were used to normalize raw data. The progress curves were calculated from the quantity and normalized price data by the ICLOT$ program in the GE Time-Sharing computer.[1]

B. DATA USED IN THE QUANTITATIVE ANALYSIS

Nineteen items were used in the quantitative analysis of the effect of competition. For each of these, there were enough data to plot the sole-source and competitive procurement data separately. The procurement data are also tabulated. In addition to the table and the progress curve, a short resume of the production history is given for each item. A summary of the essential data on these 18 items of equipment is displayed in Table H-0.

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[1] The ICLOT$ program was originally prepared by personnel of the Defense Contract Audit Agency. A complete description of the technique may be found in DCAAM 7640.1 [3].

Table H-G. PRINCIPAL DATA ON ITEMS USED IN QUANTITATIVE ANALYSIS OF COMPETITION

Item	Number of Sole-Source Units	Number of Units in First Competitive Buy	Calculated Sole-Source First-Unit Cost (1970 $)	Slope of Sole-Source Progress Curve (percent)	Unit Cost, First Competitive Buy (1970 $)
1. BULLPUP (Martin)	10,195	1,078	121,850	78.5	3,725
BULLPUP (Maxson)	4,438	3,580	10,006	90.2	1,474
2. TALOS G&C Unit	1,605	470	1,200,370	82.6	87,636
3. TD-660 Multiplexer	2,175	425	239,167	70.9	3,524
4. TD-352 Multiplexer	1,383	2,218	16,497	95.8	4,291
5. TD-202 Radio Combiner	827	2,185	19,680	87.4	1,741
6. TD-204 Cable Combiner	2,687	5,943	31,668	84.2	1,877
7. HAWK [illegible]	8,128	2,246	55,761	74.1	1,014
8. APX-72 Airborne Transponder	13,250	3,373	66,377	78.8	1,653
9. MK-48 Warhead	552	480	34,000	88.8	5,087
MK-48 Electrical Assembly	617	417	77,601	80.6	6,027
10. Aerno 60-6402	535	39	10,520	95.6	3,030
11. SPA-25 Radar Indicator	1,631	323	271,523	72.7	6,819
12. SHILLELAGH Missile	1,393	21,512	152,622	76.0	3,041
13. ROCKEYE Bomb	35,855	32,087	32,770	83.4	1,641
14. TOW Missile	24,750	12,000	15,540	91.1	1,999
15. USM-181 Telephone Test Set	642	357	4,751	82.1	422
16. FGC-20 Teletype Set	1,704	276	2,678	97.0	1,308
17. MD-522 Modulator-Demodulator	2,542	697	18,480	85.9	1,275
18. CV-1548 Signal Converter	3,945	7,638	37,414	62.7	1,503

1. BULLPUP Missile Guidance, Control, and Airframe

The Guidance, Control, and Airframe (GC&A) subsystem of the BULLPUP, an air-to-ground missile, was procured initially on a sole-source basis from the Martin Corporation, but after one multi-year buy (in 1961), it was decided to switch to a competitive procurement method. The intent was to qualify a second vendor and, after a period of split buys from both producers (to enable the second source to achieve a truly competitive posture), to have a winner-take-all competition. In FY 61, the Maxson Corporation won the bidding, to become the second source; and both Maxson and Martin produced BULLPUPs during the period FY 61-63. The FY-64 winner-take-all buy was won by Maxson. Table H-1 shows the price-quantity data for each firm, and Figure H-1 shows the progress curves for the two suppliers.

Table H-1. PRICE-QUANTITY DATA FOR THE BULLPUP MISSILE GC&A

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Martin	58	Sole-source	700	18,000
	59	Sole-source	2,315	9,203
	60	Sole-source	3,805	5,693
	61	Sole-source	3,375	4,969
	61	Competitive*	1,078	3,725
	62	Competitive*	6,363	3,247
	62	Competitive*	9,541	3,121
	63	Competitive*	6,355	2,518
	63	Competitive*	2,800	2,518
Maxson	61	Competitive*	200	6,226
	62	Competitive*	1,000	3,534
	63	Competitive*	3,238	3,134
	64	Competitive	3,580	1,474

*Split buys.

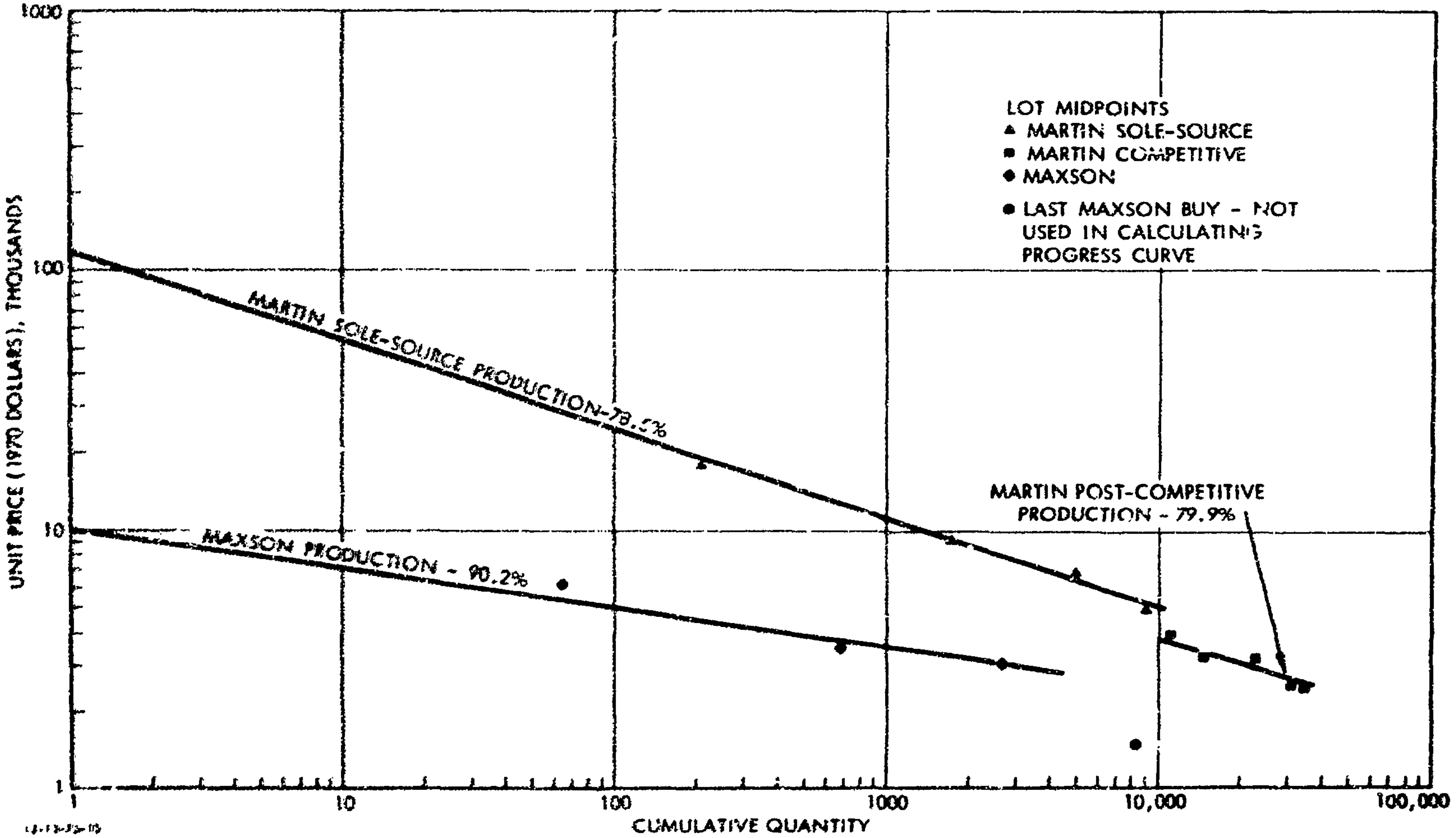


Figure H-1. PRICE-QUANTITY RELATIONSHIP FOR THE BULLPUP MISSILE GC&A

2. TALOS Missile Guidance and Control Unit

The original award for the guidance and control unit for the TALOS, a Navy surface-to-surface missile, was won by the Bendix Corporation. In the period FY 58-60, Bendix produced 592 units under sole-source awards; however, the price data for these units could not be obtained. During FY 61-65, Bendix continued to produce under sole-source contracts, and the price data for these awards was available and is tabulated. In FY 66, the procurement method was changed to competitive; and with four companies bidding, Bendix won the multi-year FY 66-68 procurement. which was the last buy of this item. Table H-2 shows the price-quantity data, and Figure H-2 shows the single progress curve (for Bendix).

Table H-2. PRICE-QUANTITY DATA FOR THE TALOS MISSILE G&C UNIT

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Bendix	58-60	Sole-source	592	(unknown)
	61	Sole-source	178	218,506
	62	Sole-source	407	166,232
	63	Sole-source	240	179,854
	64	Sole-source	94	162,822
	65	Sole-source	94	159,263
	66*	Competitive	470	87,636

*Multi-year buy.

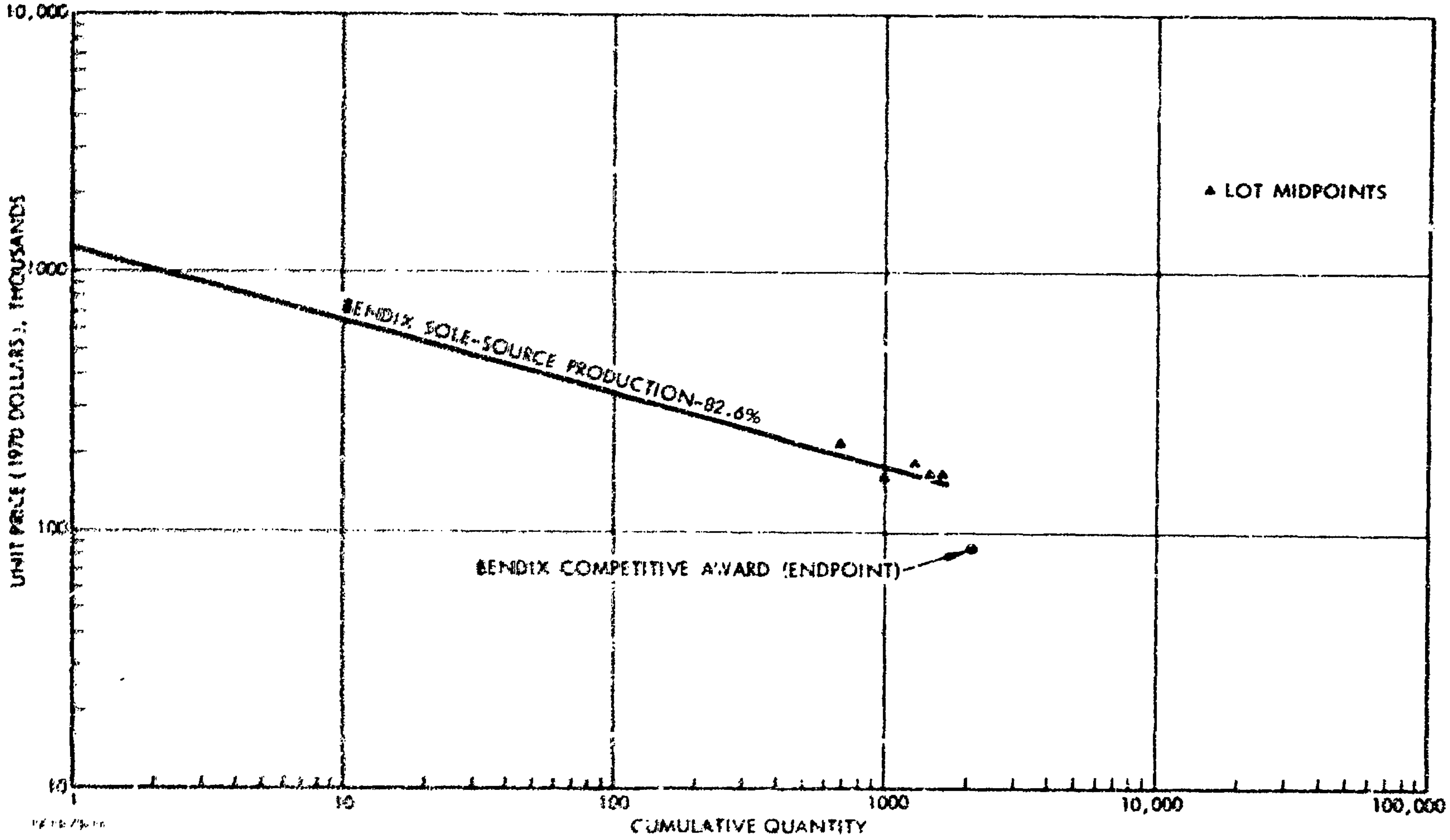


Figure H-2. PRICE-QUANTITY RELATIONSHIP FOR THE TALOS MISSILE G&C UNIT

3. TD-660 Multiplexer

The Raytheon Corporation was the original supplier of the TD-660 Multiplexer, an electronic device which converts voice-frequency signals in several communications channels to a time-division multiplex, pulse-code-modulated signal. The first four buys of the equipment were negotiated (sole-source) with Raytheon, but in FY 69 the procurement method was made competitive and was won by the Honeywell Corporation. Table H-3 shows the price-quantity data, and Figure H-3 shows the progress curves for Raytheon and Honeywell.

Table H-3. PRICE-QUANTITY DATA FOR THE TD-660 MULTIPLEXER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Raytheon	67	Sole-source	400	22,240
	68	Sole-source	350	11,945
	69	Sole-source	355	8,280
	69	Sole-source	1,070	5,943
Honeywell	69	Competitive	425	3,524
	69	Competitive	993	3,228

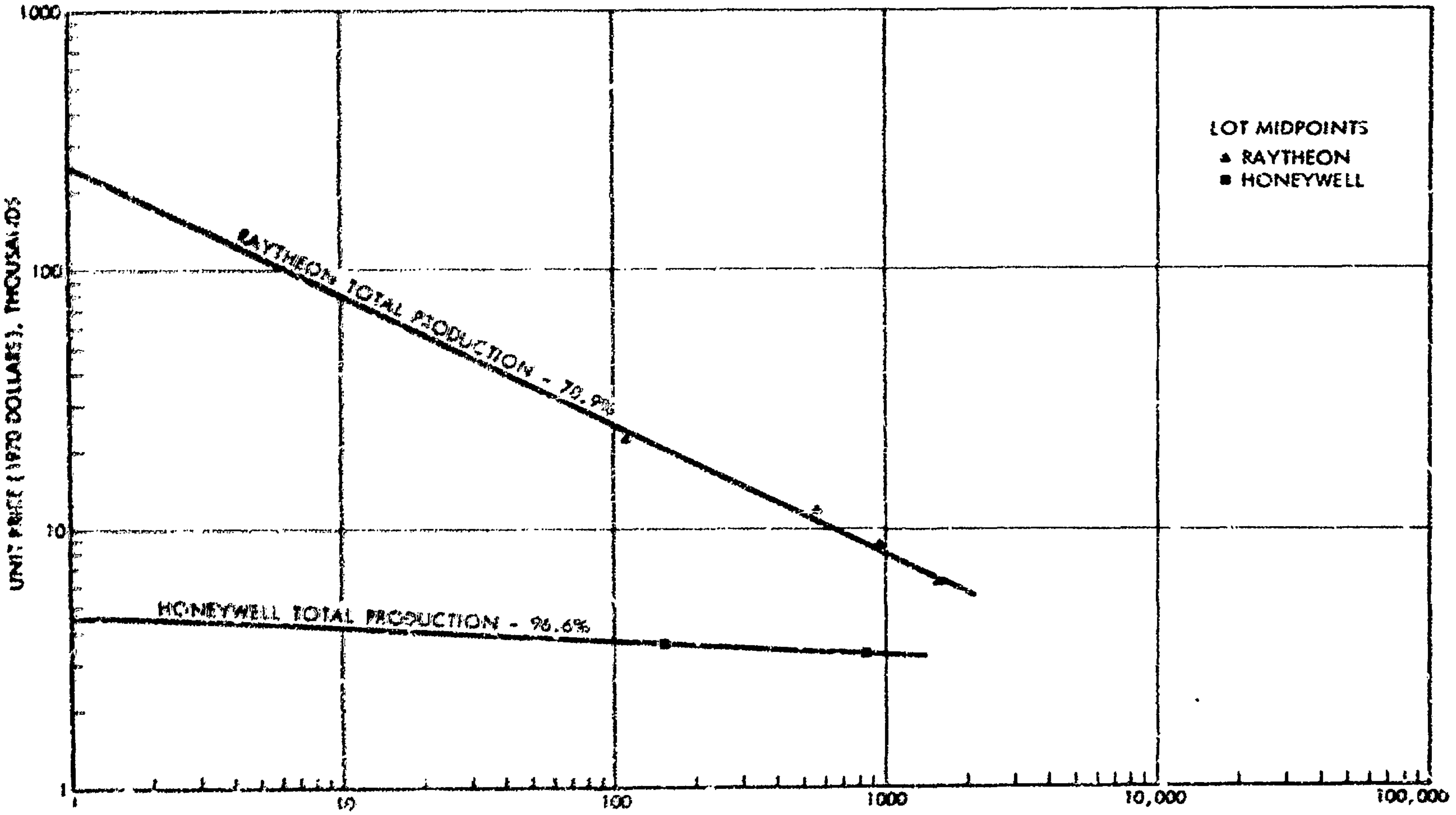


Figure H-3. PRICE-QUANTITY RELATIONSHIP FOR THE TD-660 MULTIPLEXER

4. TD-352 Multiplexer

Just as with the TD-660, the TD-352 Multiplexer was originally supplied by the Raytheon Corporation, which furnished the equipment for four successive buys under a single sole-source contract. Different unit prices were negotiated for each buy. In 1968, the procurement method was changed to competitive, and the Honeywell Corporation won both this contract and the succeeding one. Table H-4 shows the price-quantity data, and Figure H-4 shows the progress curves for Raytheon and Honeywell.

Table H-4. PRICE-QUANTITY DATA FOR THE TD-352 MULTIPLEXER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Raytheon	65	Sole-source	560	11,901
	66	Sole-source	61	9,553
	67	Sole-source	675	10,916
	68	Sole-source	87	10,269
Honeywell	68	Competitive	2,218	4,291
	69	Competitive	140	4,114

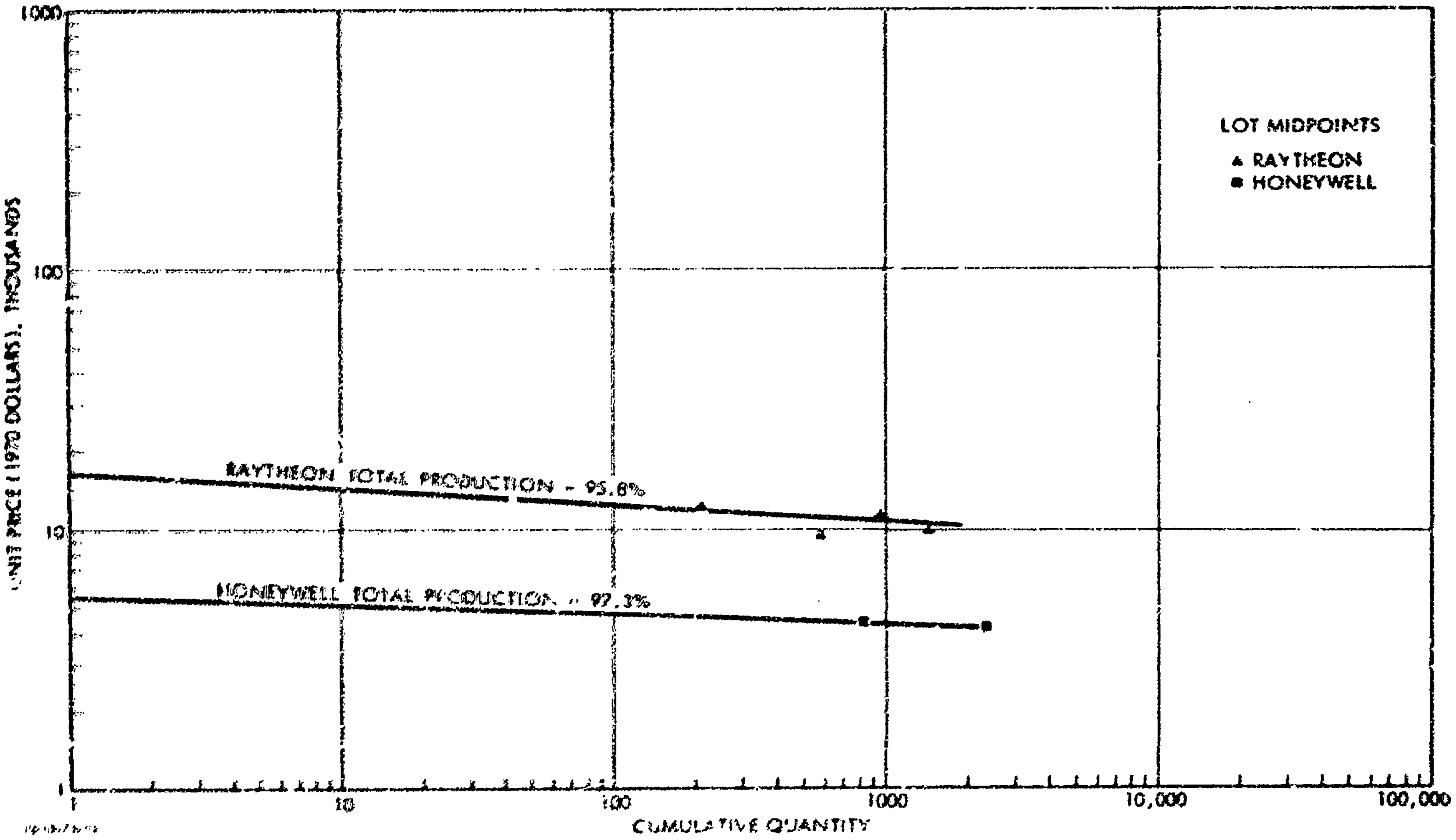


Figure H-4. PRICE-QUANTITY RELATIONSHIP FOR THE TD-352 MULTIPLEXER

5. TD-202 Radio Combiner

The TD-202 Radio Combiner is a device used as a radio transmission interface unit, which accepts outputs from multiplexers and processes them for transmission. It is also used at radio repeater stations and as interface units at radio-to-cable conversion terminals. The pattern of the previous two items is repeated for the TD-202. The Raytheon Corporation received the first sole-source contract in 1965 and was the only vendor until Honeywell won the competitive contract in 1967. Although Honeywell again won the 1968 competition, 170 units were also purchased in that year from Raytheon under the existing sole-source contract. The price-quantity data are displayed in Table H-5, and Figure H-5 shows the progress curves for Raytheon and Honeywell.

Table H-5. PRICE-QUANTITY DATA FOR THE TD-202 RADIO COMBINER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Raytheon	65	Sole-source	280	8,220
	66	Sole-source	422	5,817
	67	Sole-source	185	5,623
	68	Sole-source	170	3,366
Honeywell	68	Competitive	2,185	1,741
	68	Competitive	450	1,735

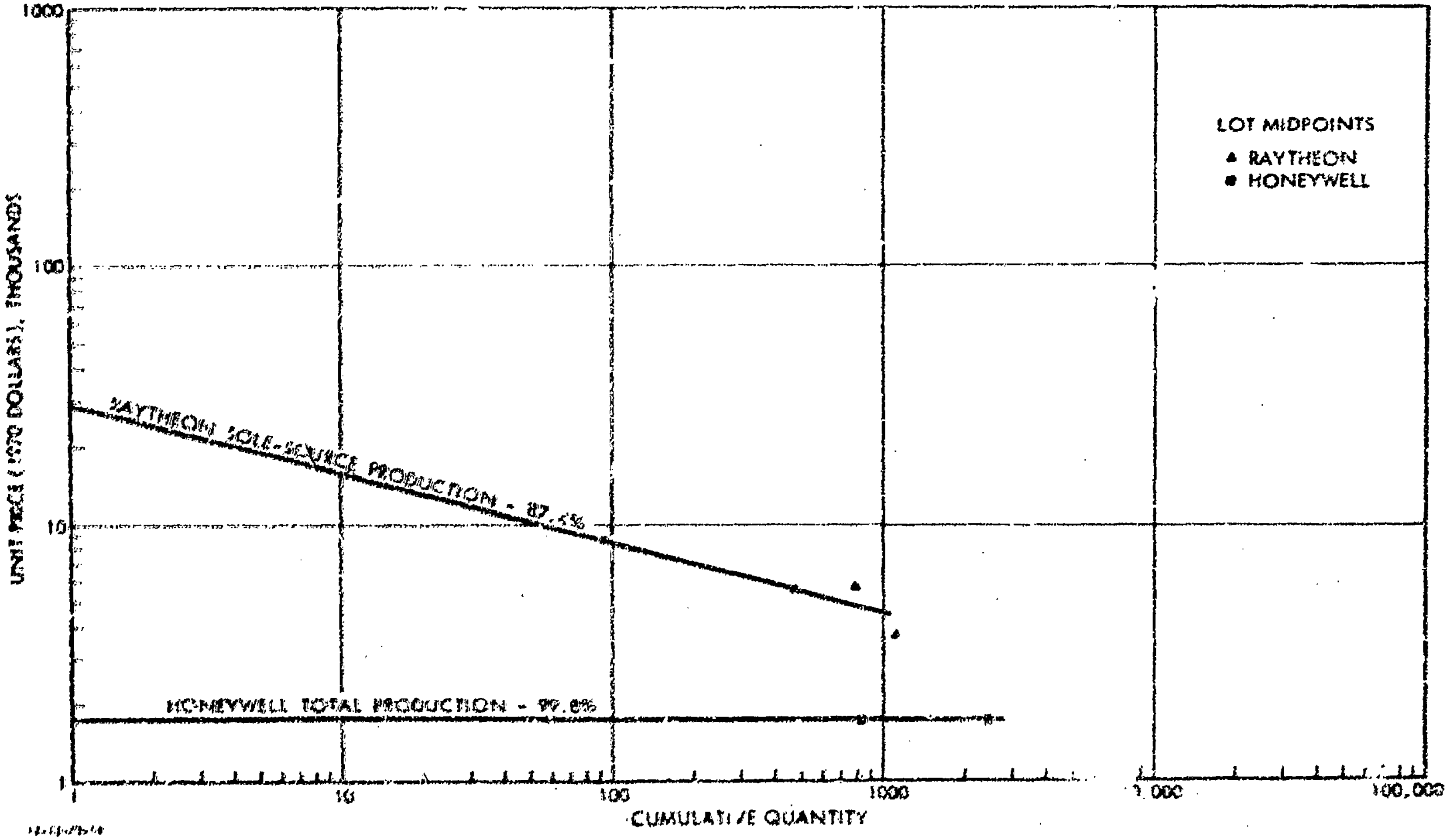


Figure H-5. PRICE-QUANTITY RELATIONSHIP FOR THE TD-202 RADIO COMBINER

6. TD-204 Cable Combiner

The TD-204 Cable Combiner is an interface device used between a multiplexer and a coaxial cable in a cable communication link. It processes signals to convert them to a form acceptable for cable transmission and demultiplexing. It is also used as a repeater and as an interface unit in radio-to-cable conversion stations. The TD-204 is the last of the items with the Raytheon-Honeywell pattern. Raytheon received the initial sole-source contract in 1965 (renegotiated in FY 67) and was the only vendor for negotiated prices under that contract until 1968. At this time the procurement was made competitive, and Honeywell won the subsequent two contracts. Table H-6 shows the price-quantity data, and Figure H-6 shows the Raytheon and Honeywell progress curves.

Table H-6. PRICE-QUANTITY DATA FOR THE TD-204 CABLE COMBINER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Raytheon	67	Sole-source	760	7,726
	67	Sole-source	255	6,696
	67	Sole-source	633	5,793
	68	Sole-source	484	5,506
	68	Sole-source	555	3,755
Honeywell	68	Competitive	5,943	1,877
	69	Competitive	145	1,763

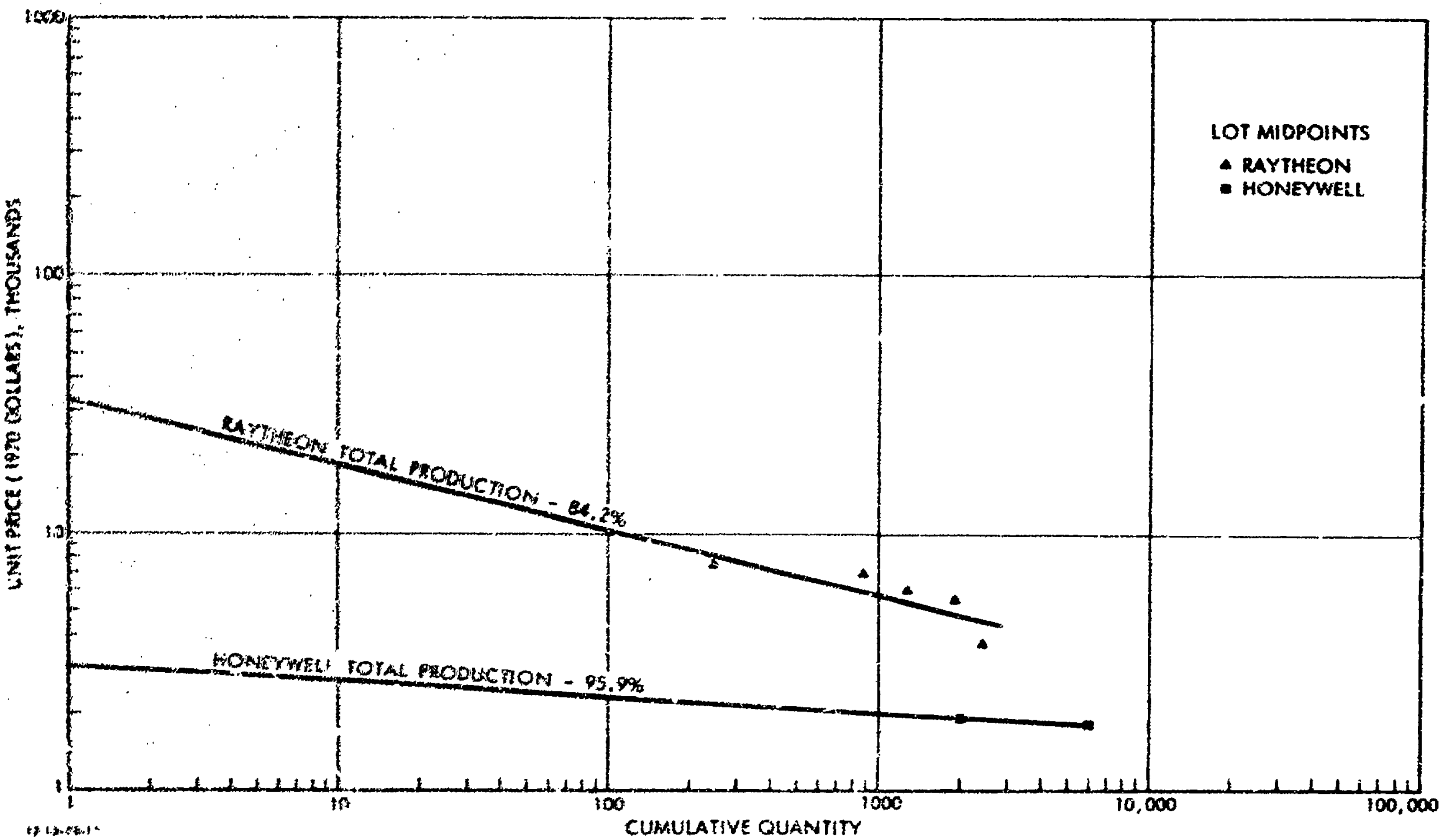


Figure H-6. PRICE-QUANTITY RELATIONSHIP FOR THE TD-204 CABLE COMBINER

7. HAWK Missile Motor Metal Parts

The HAWK is a ground-to-air missile weapon system produced by Raytheon. After the first three years of production, the HAWK motor metal parts were bought by the Army Missile Command (MICOM) as Government Furnished Equipment (GFE). Aerojet General Corporation was the contractor for the HAWK motor metal parts for the first six years of production, both as a subcontractor to Raytheon and as a prime to MICOM. In the period FY 62-63, MICOM decided to introduce competition; and the subsequent three competitive contracts were won by the Intercontinental Manufacturing Company. Table H-7 shows the price-quantity data, and Figure H-7 shows the progress curves for Raytheon and Intercontinental.

Table H-7. PRICE-QUANTITY DATA FOR THE HAWK MISSILE MOTOR METAL PARTS

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Aerojet General	57	Sole-source	200	(unknown)
	58	Sole-source	256	3,593
	59	Sole-source	1,366	3,018
	60-61	Sole-source	4,300	1,622
	62	Sole-source	2,006	1,186
Intercontinental	63	Competitive	2,346	1,014
	64	Competitive	1,545	814
	64	Competitive	2,279	795

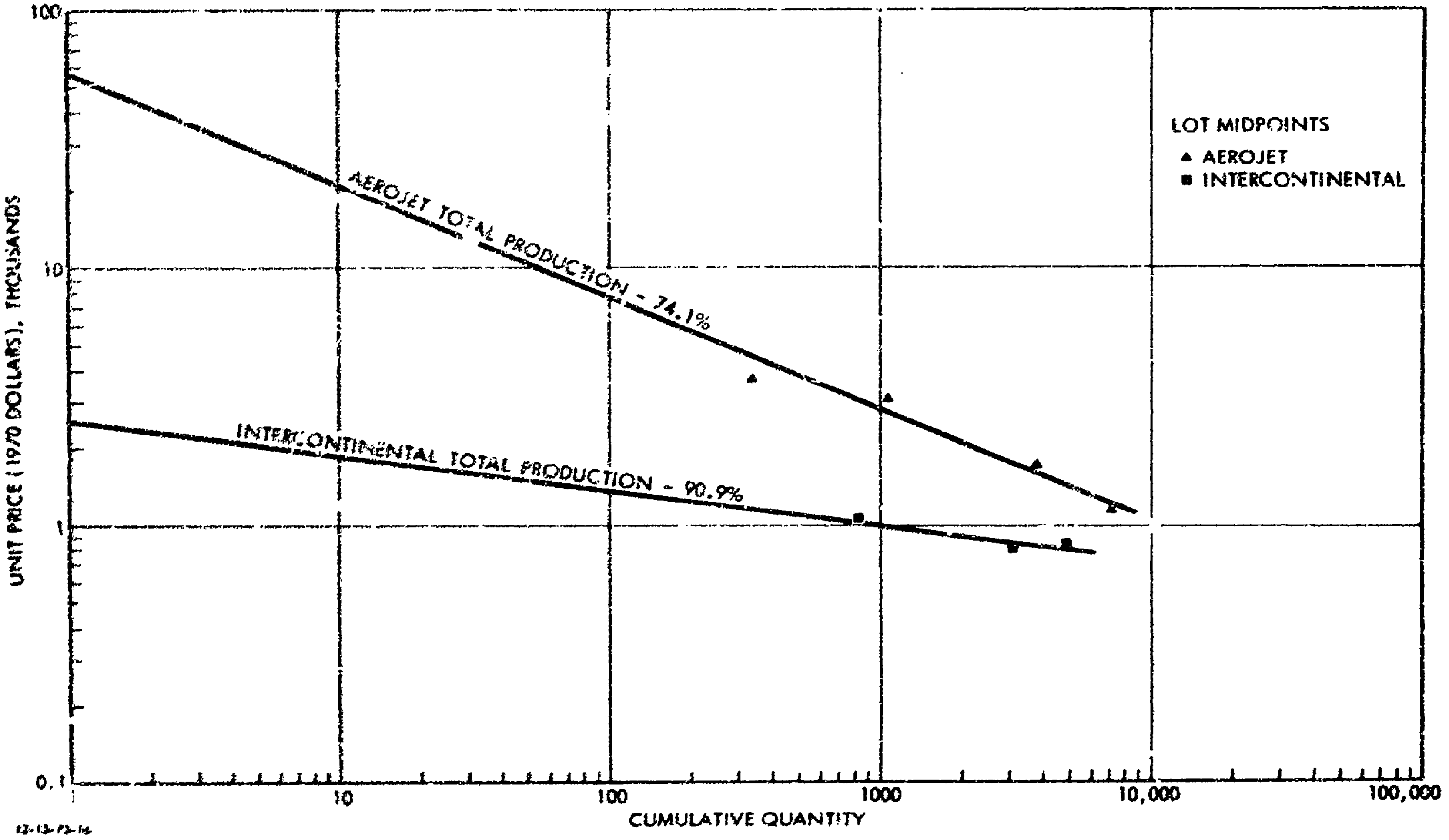


Figure H-7. PRICE-QUANTITY RELATIONSHIP FOR THE HAWK MISSILE MOTOR METAL PARTS

8. APX-72 Airborne Transponder

The APX-72 transmits identification codes when interrogated by friendly radars. It was originally produced under a sole-source contract with the Bendix Corporation. After the first production, it was decided to make the procurement competitive; but additional units were required before all the documentation needed for competition was ready, and a second sole-source contract was given to Bendix. The multi-year competitive contract in FY 70 was won by the Honeywell Corporation, and all the subsequent production was under that contract. There are two models of the APX-72 (the RT859 and the RT859A), and it is virtually impossible to determine whether the learning from the RT859 should be carried over altogether to the RT859A production or whether the two models should be treated separately. The price-quantity data for both models are shown in Table H-8, and the progress curves for Bendix and Honeywell are shown in Figure H-8. The curves are shown for only the RT859 production.

Table H-8. PRICE-QUANTITY DATA FOR THE APX-72 AIRBORNE TRANSPONDER

Model	Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
RT859	Bendix	70	Sole-source	10,887	4,150
RT859		71	Sole-source	2,363	2,636
RT859A		71	Sole-source	1,150	2,580
RT859	Honeywell	70	Competitive	3,373	1,653
RT859		71	Competitive	1,687	1,553
RT859		71	Competitive	1,500	1,511
RT859A		71	Competitive	3,798	1,790
RT859A		72	Competitive	2,302	1,418
RT859A		72	Competitive	469	1,396

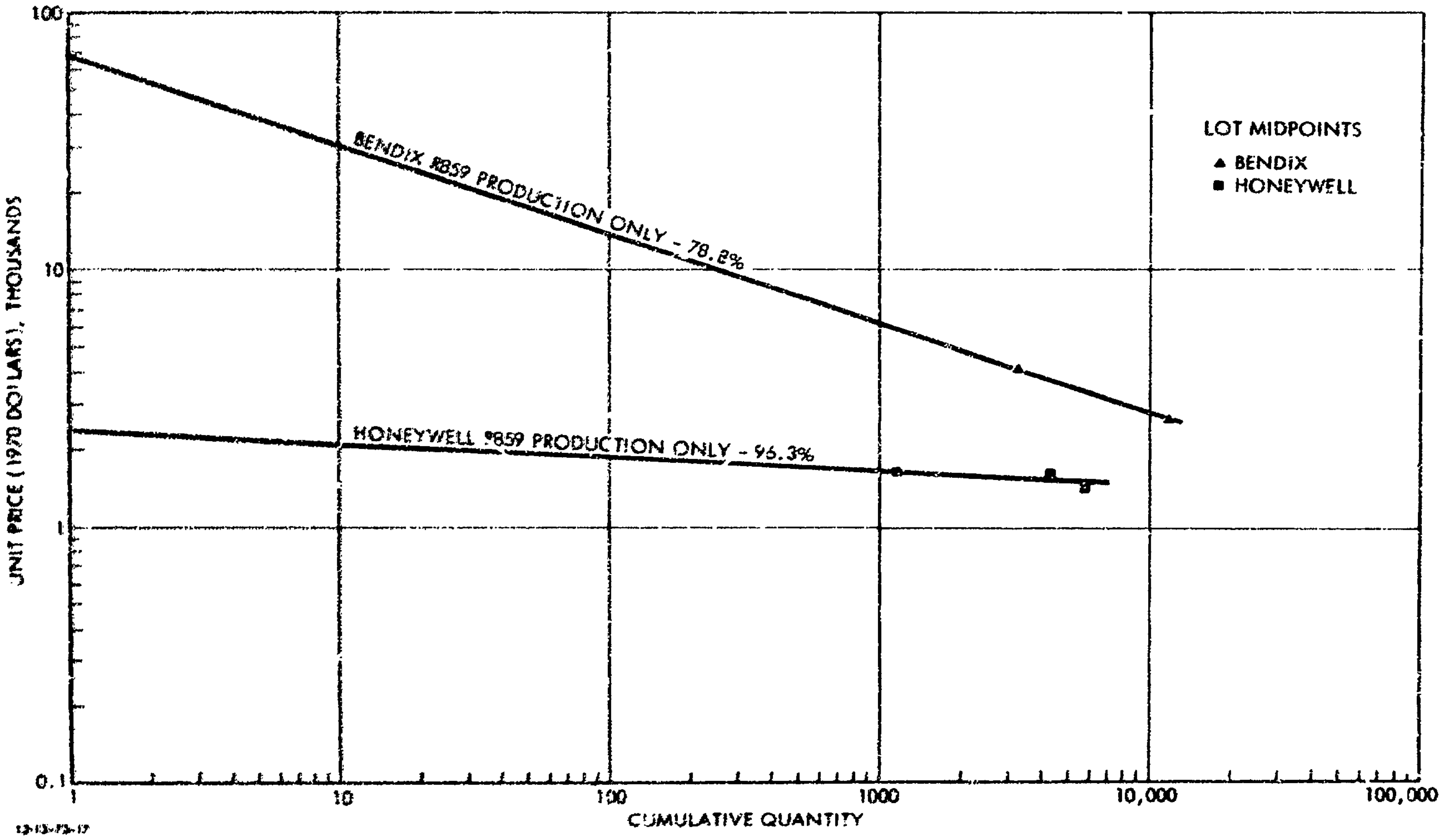


Figure H-8. PRICE-QUANTITY RELATIONSHIP FOR THE APX-72 AIRBORNE TRANSPONDER

9. MK-48 Torpedo Components

Four major components of the MK-48 Torpedo (the Warhead, the Exploder, the Electric Assembly, and the Test Set) were first produced by the Delco Corporation under sole-source contracts and later by the Goodyear Aerospace Company when the procurement was made competitive. The price-quantity data are shown in Table H-9, and the progress curves, or points, are shown in Figure H-9. Since the methodology for the quantitative analysis of the effect of competition requires a sole-source progress curve, only the data on the Warhead and the Electric Assembly could be used, there being only one sole-source data point each for the Exploder and the Test Set.

Table H-9. PRICE-QUANTITY DATA FOR THE MK-48 TORPEDO COMPONENTS

Component - Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Warhead - Delco	70	Sole-source	48	15,500
	71	Sole-source	47	19,391
	72	Sole-source	457	11,019
Warhead - Goodyear Aerospace	73	Competitive	480	5,087
Exploder - Delco	70	Sole-source	58	25,800
Exploder - Goodyear Aerospace	72	Competitive	480	5,165
	73	Competitive	492	5,643
Electric Assembly - Delco	71	Sole-source	71	29,053
	72	Sole-source	546	13,356
Electric Assembly - Goodyear Aerospace	73	Competitive	417	6,027
Test Set - Delco	70	Sole-source	4	69,525
Test Set - Goodyear Aerospace	72	Competitive	34	14,717
	73	Competitive	6	17,537

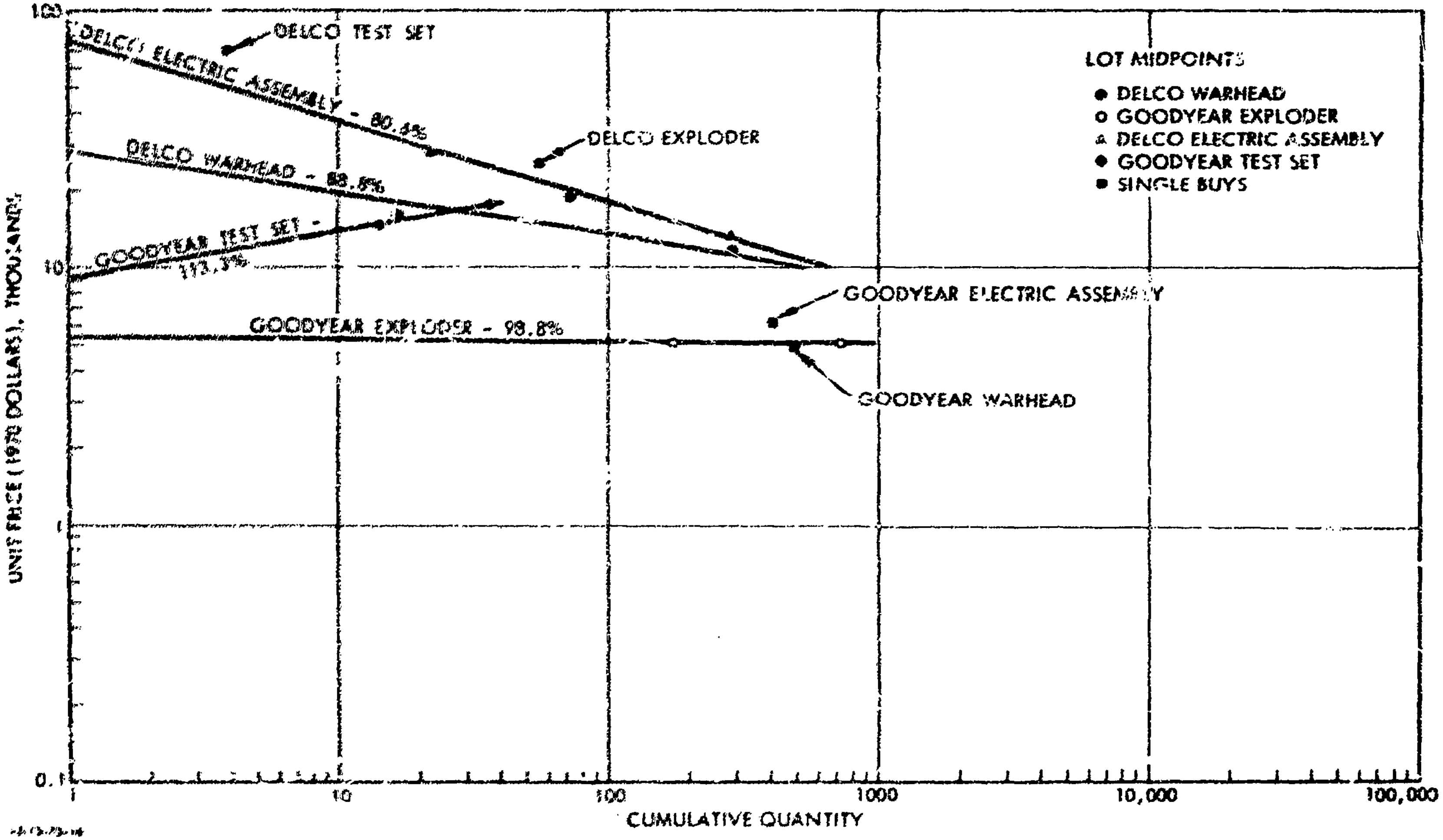


Figure H-9. PRICE-QUANTITY RELATIONSHIP FOR THE MK-48 TORPEDO COMPONENTS

10. Aerno 60-6402 Electronic Control Amplifier

The Aerno 60-6402 was the first produced under a sole-source contract awarded to the General Electric Corporation in 1966. GE won four procurements of the item by sole-source negotiation until 1969, when the procurement method was made competitive and was won by the Lear-Siegler Corporation. The price-quantity data are shown in Table H-10, and the progress curves for both GE and Lear-Siegler are shown in Figure H-10.

Table H-10. PRICE-QUANTITY DATA FOR THE AERNO 60-6402 ELECTRONIC CONTROL AMPLIFIER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
General Electric	66	Sole-source	70	8,988
	67	Sole-source	194	7,184
	68	Sole-source	249	7,410
	68	Sole-source	22	6,927
Lear-Siegler	69	Competitive	39	3,030
	71	Competitive	80	3,314
	72	Competitive	12	3,314

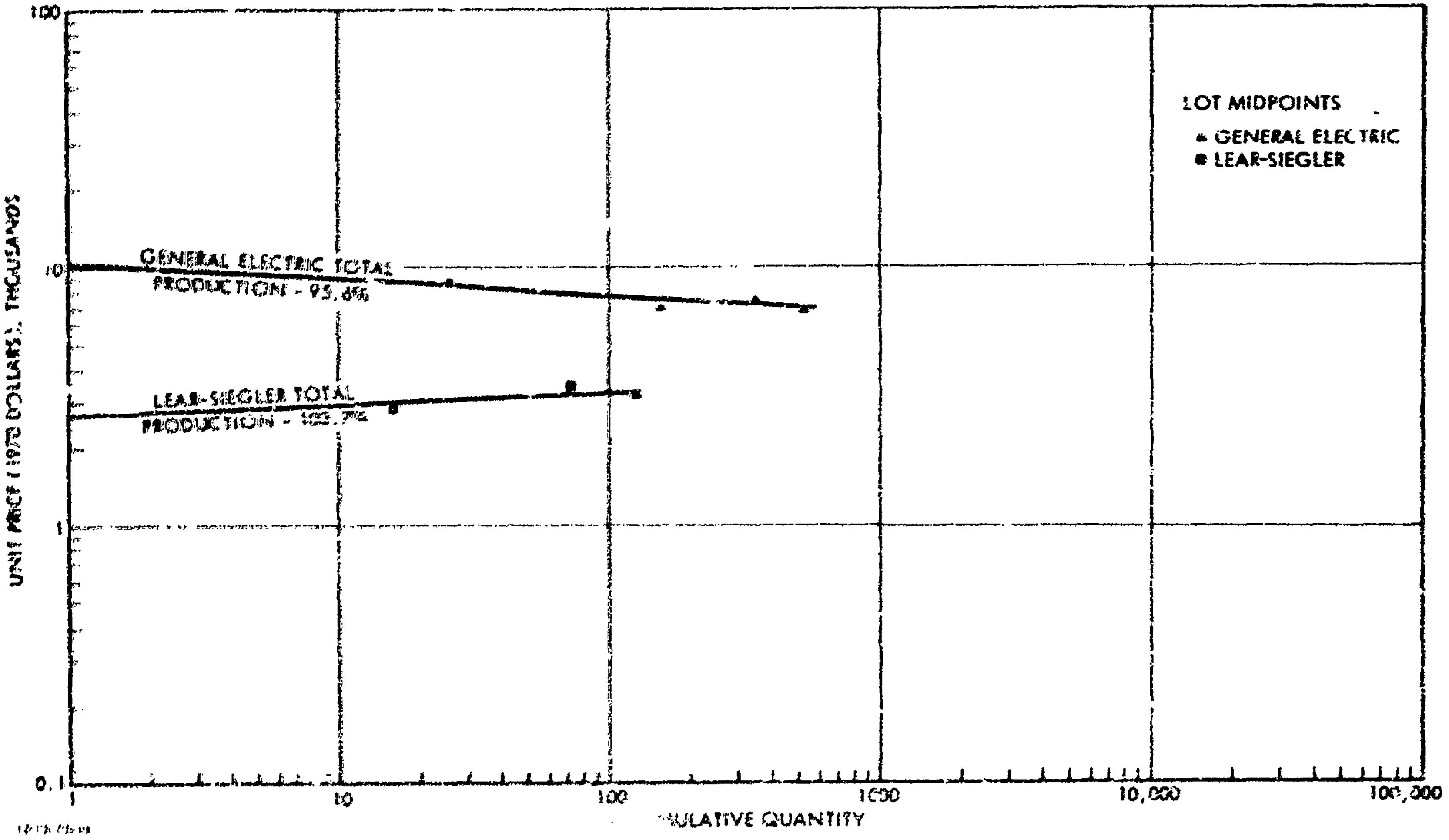


Figure H-10. PRICE-QUANTITY RELAT IP FOR THE AERNO 60-6402 ELECTRONIC CONTROL AMPLIFIER

11. SPA-25 Radar Indicator

The SPA-25 Radar Indicator was produced by the Motorola Company under sole-source contracts during the period 1964-69. The procurement method was made competitive in 1970 and was won by the Litton Precision-Clifton Company. There is strong evidence that the first unit price charged by Motorola was unrealistically low and did not cover the costs of production; and for this reason the price was not used in the quantitative analysis of the effects of competition, although the first production quantity was considered. The first Litton unit price seems very low also, and their subsequent prices are much higher. The price-quantity data are shown in Table H-11, and the progress curves are shown in Figure H-11.

Table H-11. PRICE-QUANTITY DATA FOR THE SPA-25 RADAR INDICATOR

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Motorola	64	Sole-source	819	6,320
	67	Sole-source	555	10,841
	68	Sole-source	97	10,679
	69	Sole-source	160	8,771
Litton Precision-Clifton	70	Competitive	323	6,819
	72	Competitive	40	8,830
	72	Competitive	17	6,704

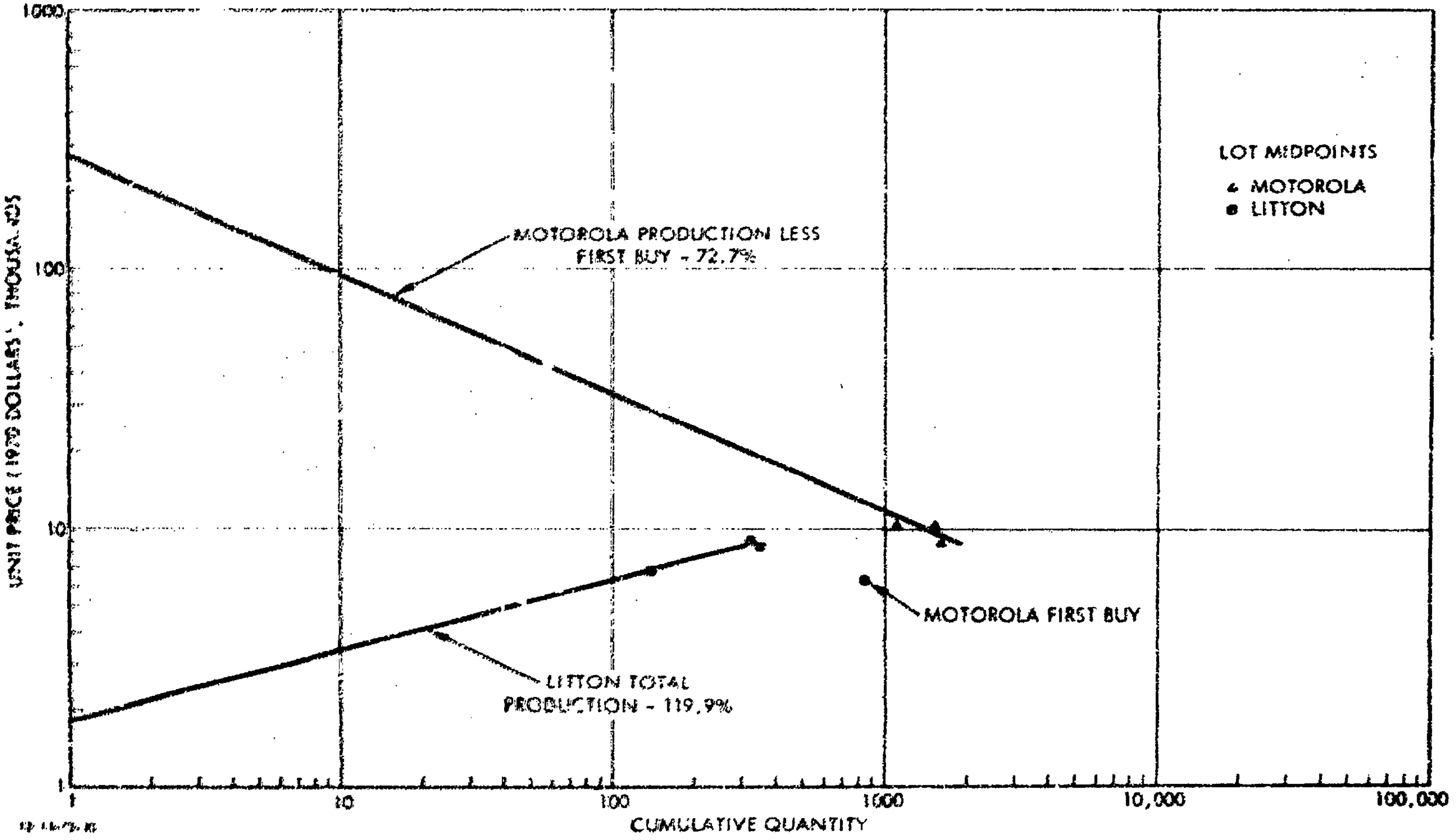


Figure H-11. PRICE-QUANTITY RELATIONSHIP FOR THE SPA-25 RADAR INDICATOR

12. SHILLELAGH Missile

The Army SHILLELAGH gun-launched tactical missile was first developed and produced by the Philco-Ford Corporation under sole-source negotiation. It was then decided to qualify a second source for the missile and to divide subsequent procurement between the two sources according to a modified competition: Each vendor would get some of the buy, but the split would be determined by the prices bid. The Martin-Marietta Company won the competition to become the second source, and from the end of 1966 through 1969 both Philco and Martin produced the SHILLELAGH. The price-quantity data are shown in Table H-12, and the progress curves for Philco and Martin are shown in Figure H-12.

Table H-12. PRICE-QUANTITY DATA FOR THE SHILLELAGH MISSILE

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Philco-Ford	66	Sole-source	1,393	14,141
	67	Sole-source	16,552	4,484
	68	Competitive*	21,846	2,673
	69	Competitive*	35,903	2,015
Martin-Marietta	67	Competitive*	4,960	3,041
	69	Competitive*	7,540	2,385

*Split buys.

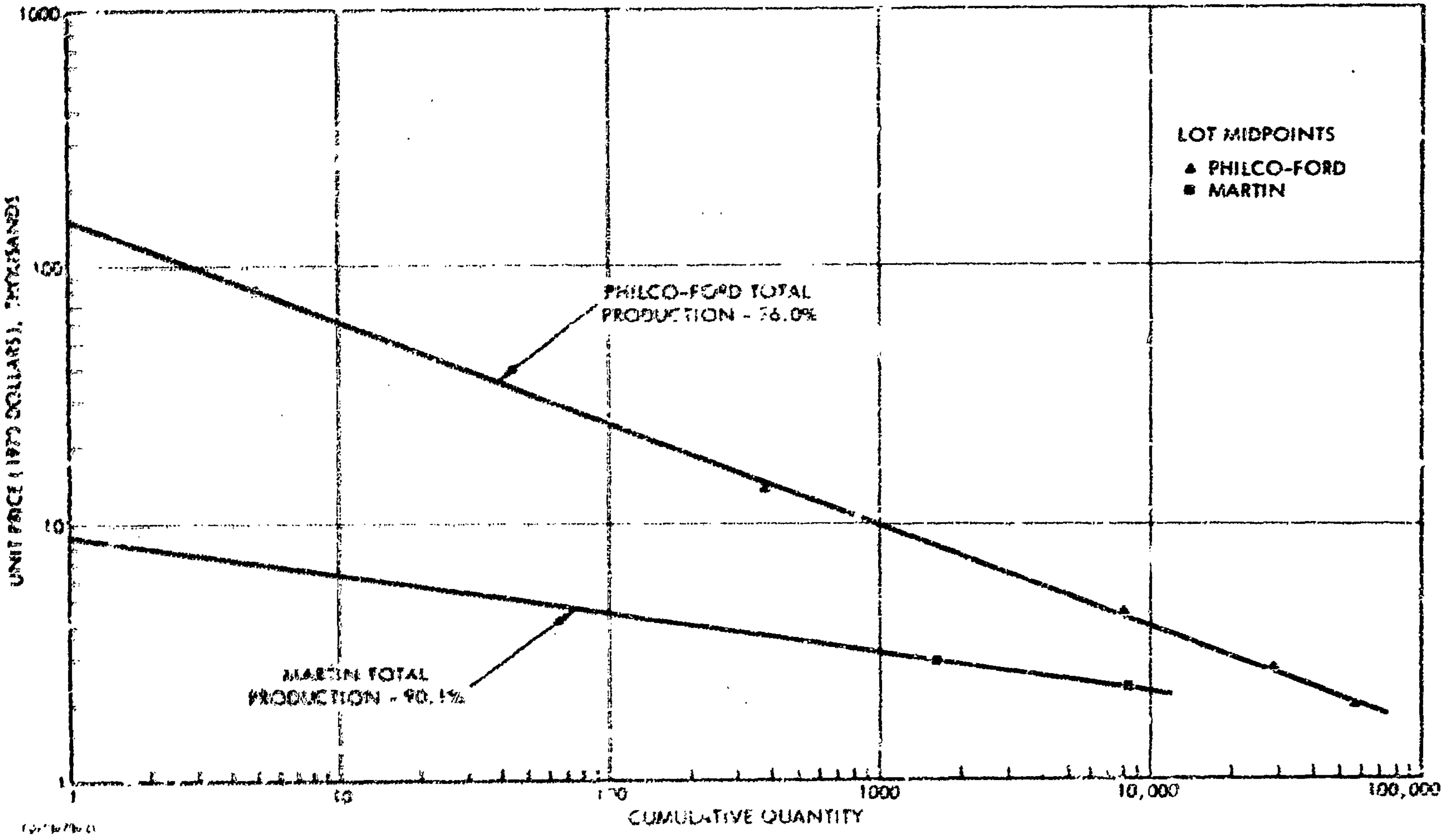


Figure H-12. PRICE-QUANTITY RELATIONSHIP FOR THE SHILLELAGH MISSILE

13. ROCKEYE Bomb

During the period 1967 through 1970, the Honeywell Corporation produced the ROCKEYE bomb under sole-source negotiated contracts. In 1971, it was decided to introduce a second source for the ROCKEYE bomb, and the Marquardt Corporation was selected. Subsequent production was divided between the two companies on the basis of their bids. Table H-13 shows the price-quantity data, and Figure H-13 shows the progress curves for both companies.

Table H-13. PRICE-QUANTITY DATA FOR THE ROCKEYE BOMB

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Honeywell	67	Sole-source	535	8,021
	68	Sole-source	4,270	4,470
	69	Sole-source	7,150	3,121
	70	Sole-source	18,100	2,344
	70	Sole-source	5,800	2,309
	72	Competitive*	18,058	1,882
	72	Competitive*	9,029	1.738
	72	Competitive*	13,431	1,769
	72	Competitive*	4,000	1,602
	73	Competitive*	2,500	1,540
	73	Competitive*	28,098	1,540
Marquardt	72	Competitive*	5,000	1,641
	72	Competitive*	2,500	1,606
	72	Competitive*	4,500	1,606
	73	Competitive*	3,500	1,734

*Split buys.

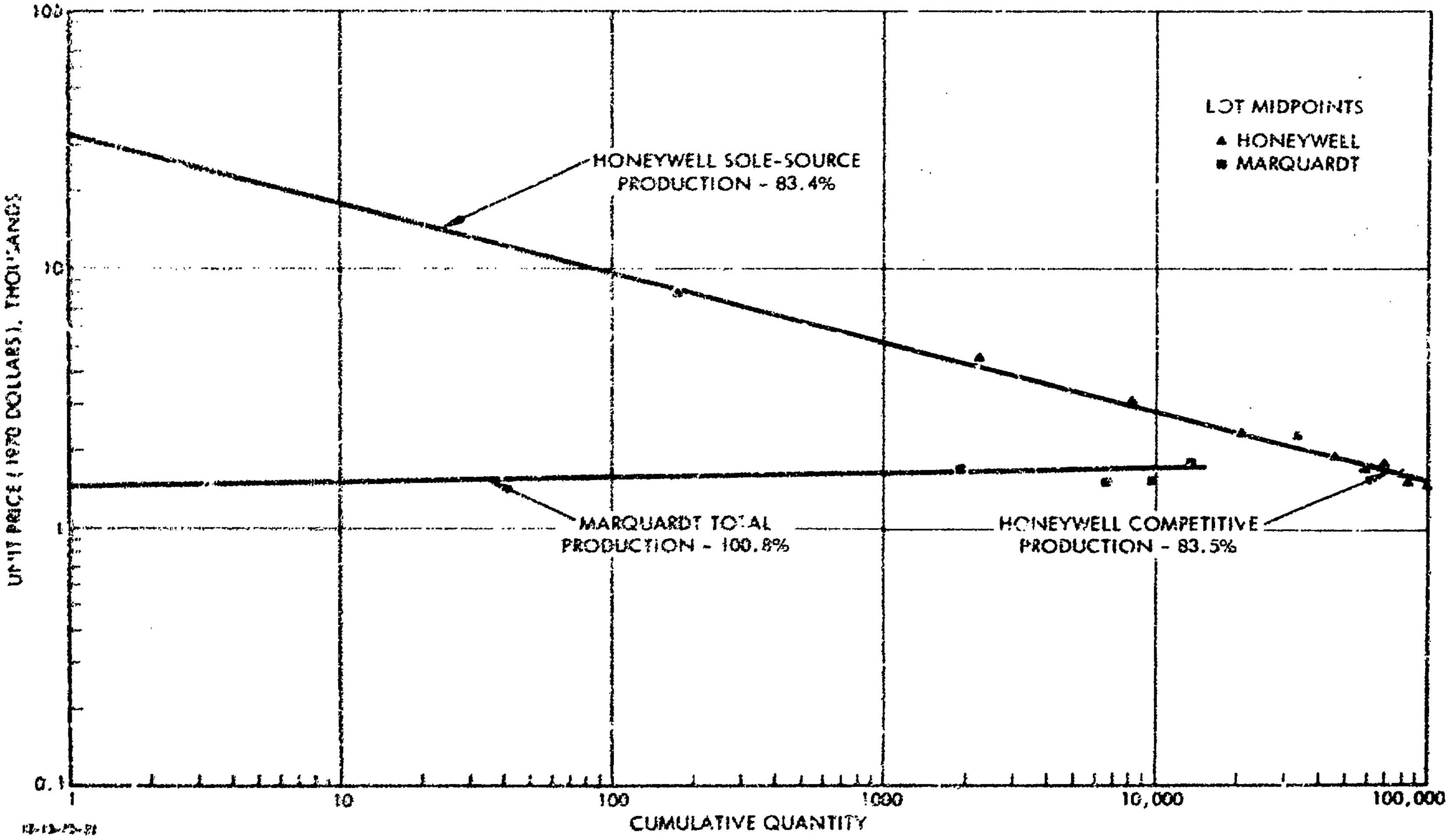


Figure H-13. PRICE-QUANTITY RELATIONSHIP FOR THE ROCKEYE BOMB

14. TOW Missile

The TOW antitank missile was developed by the Hughes Aircraft Company, which was also given the first sole-source production contract in FY 68. The Army Missile Command (MICOM) then decided to introduce a second producer and selected the Chrysler Corporation. The contract with Chrysler provided for an "educational" buy and option buys to bring Chrysler to a fully competitive position with Hughes, after which there would be a winner-take-all competition for the final multi-year buy. From FY 69 through FY 71, the TOW was produced by both Hughes and Chrysler, and in November 1971 Hughes won the buy-out competition. The price-quantity data are shown in Table H-14, and the progress curves for both Hughes and Chrysler are shown in Figure H-14.

Table H-14. PRICE-QUANTITY DATA FOR THE TOW MISSILE

Contractor	FY	Type Contract	Quantity	Unit Price (970 $)
Hughes Aircraft	69	Sole-source	5,350	5,237
	70	Sole-source	10,400	5,070
	71	Sole-source	2,500	4,062
	71	Sole-source	6,500	3,556
	72	Competitive	12,000	1,999
	73	Competitive	12,000	2,060
	74	Competitive	12,000	2,040
	75	Competitive	10,837	2,021
Chrysler Corp.	69	Sole-source*	200	19,037
	71	Sole-source*	2,685	5,329
	71	Sole-source*	4,000	4,041

*Educational awards.

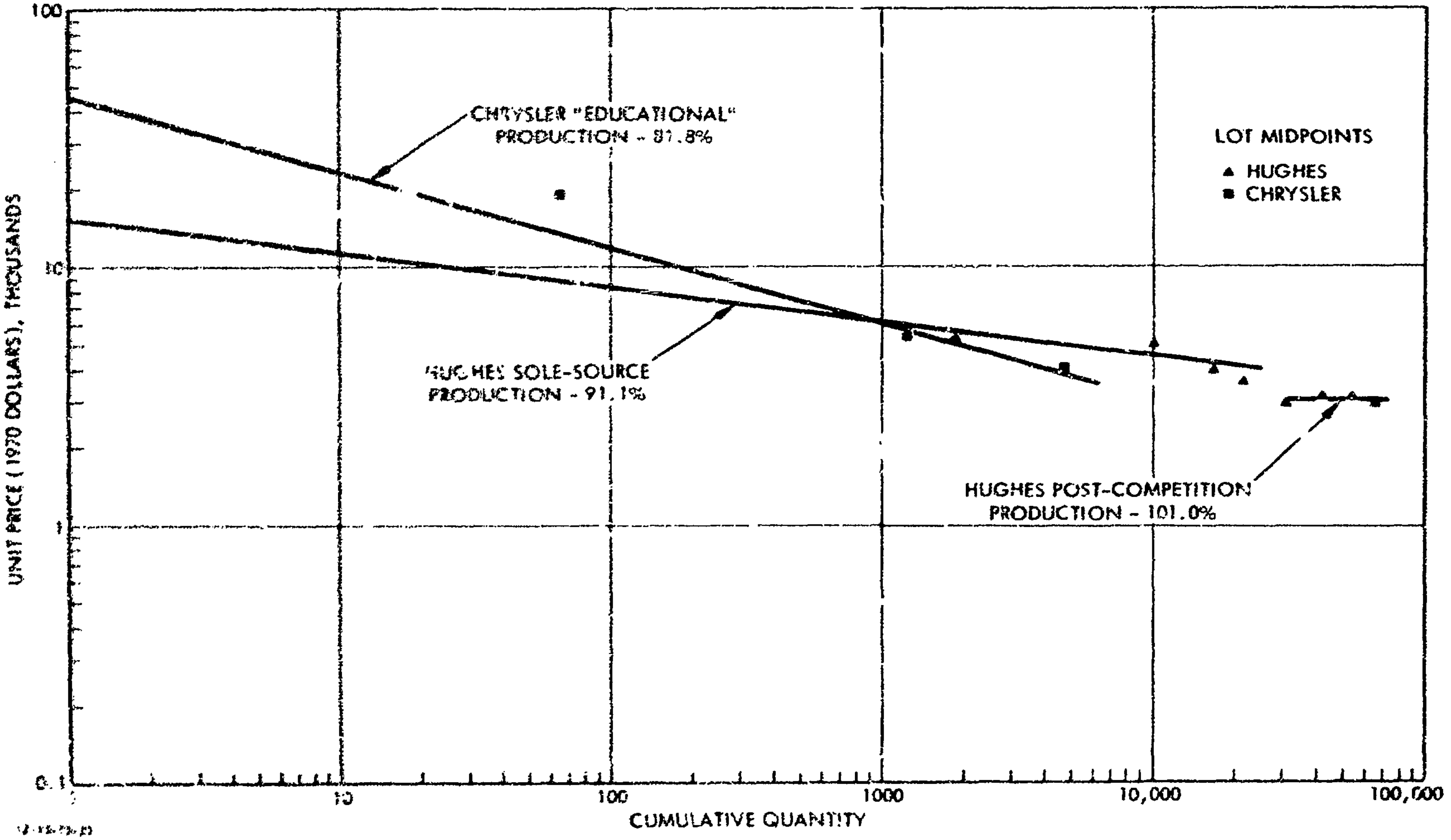


Figure H-14. PRICE-QUANTITY RELATIONSHIP FOR THE TOW MISSILE

15. USM-181 Telephone Test Set

16. FGC-20 Teletype Set

17. MD-522 Modulator-Demodulator

18. CV-1548 Signal Converter

The procurement-history data on the four items listed above were all obtained by correspondence with the U.S. Army Electronics Command (ECOM) and were for the most part limited to the information in the ECOM computerized Procurement History Data File. These data are shown in Tables H-15 through H-18. For each of these items, there were data on only one competitive buy after a number of sole-source procurements. Figures H-15 through H-18 show the progress curves for the sole-source procurements and the points for the competitive buys.

Table H-15. PRICE-QUANTITY DATA FOR THE USM-181 TELEPHONE TEST SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Hewlett-Packard	67	Sole-source	17	2,035
	69	Sole-source	33	1,303
	69	Sole-source	8	1,318
	70	Sole-source*	278	1,290
	72	Sole-source	506	734
NLS Company	72	Competitive	357	422

*Advertised, but only one bidder.

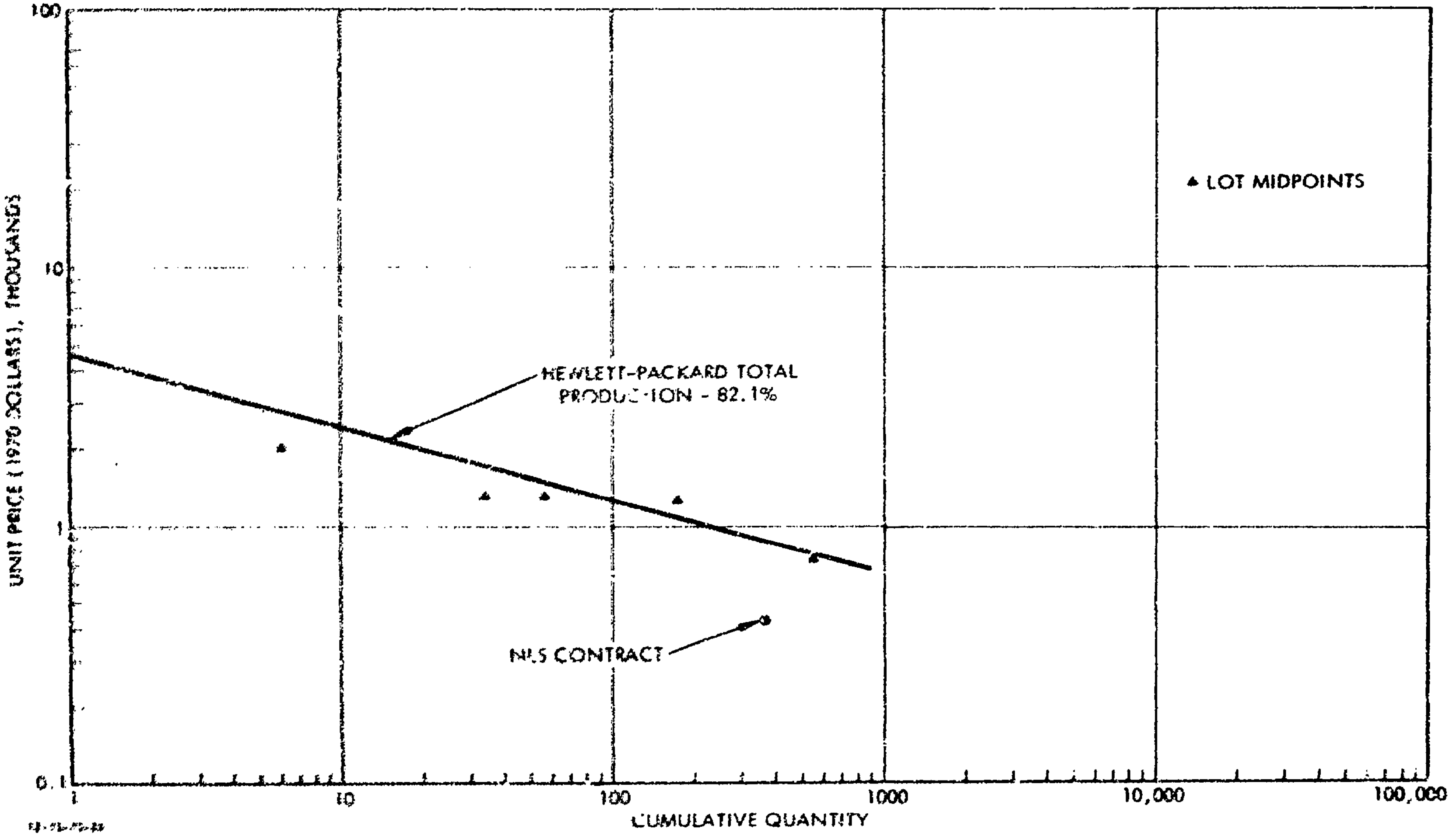


Figure H-15. PRICE-QUANTITY RELATIONSHIP FOR THE USM-181 TELEPHONE TEST SET

Table H-16. PRICE-QUANTITY DATA FOR THE FGC-20 TELETYPE SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Kleinschmidt Company	67	Sole-source	169	2,338
	67	Sole-source	690	1,976
	67	Sole-source	819	1,985
	69	Sole-source	26	2,189
Futuronics Inc.	70	Competitive	276	1,308

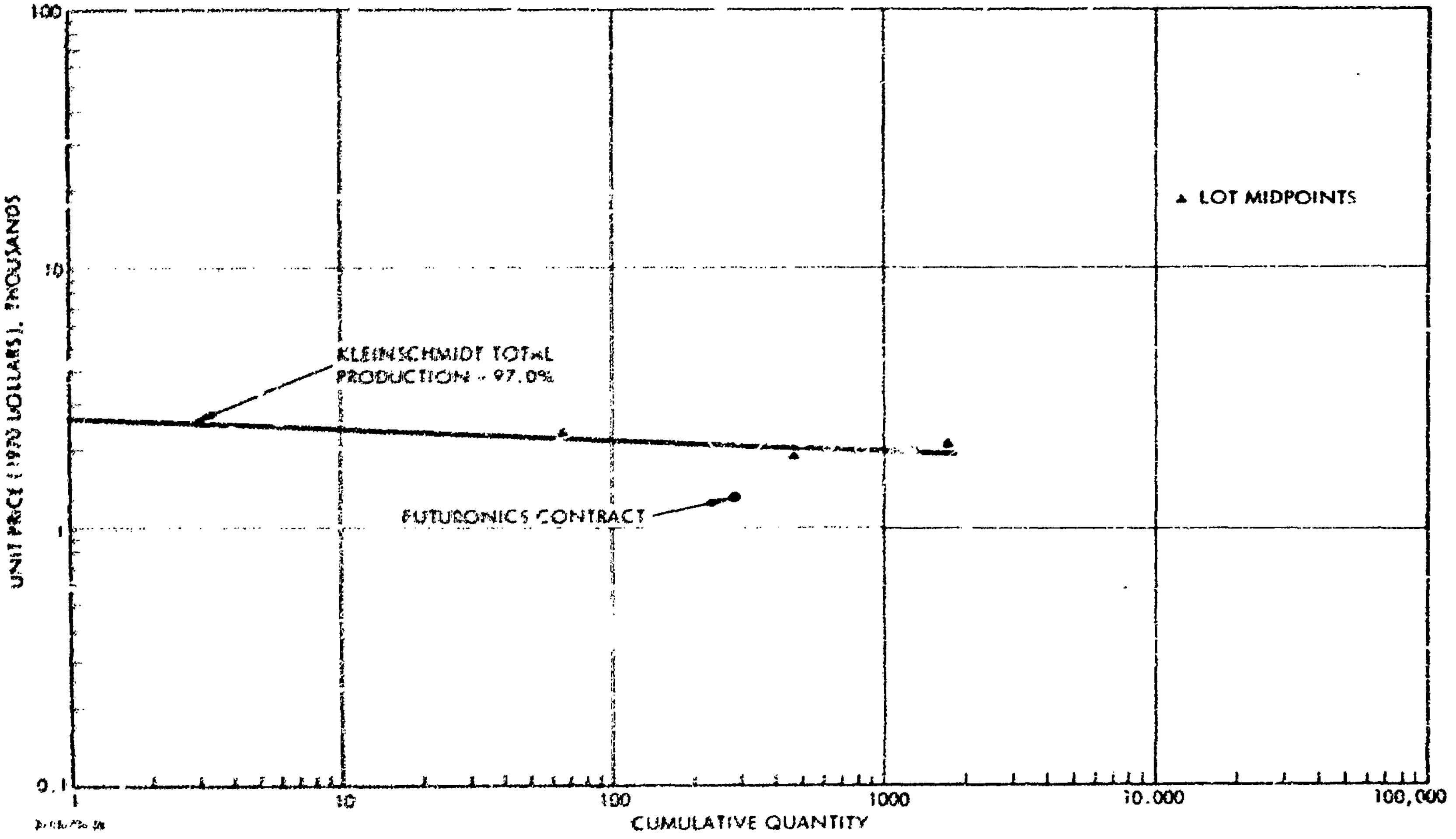


Figure H-16. PRICE-QUANTITY RELATIONSHIP FOR THE FGC-20 TELETYPE SET

Table H-17. PRICE-QUANTITY DATA FOR THE MD-522 MODULATOR-DEMODULATOR

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
General Dynamics	66	Sole-source	247	6,510
	68	Sole-source	1,288	4,466
	68	Sole-source	562	3,531
	68	Sole-source	35	3,531
	69	Sole-source	115	3,152
	69	Sole-source	295	3,052
Futuronics Inc.	70	Competitive	2,263	1,275

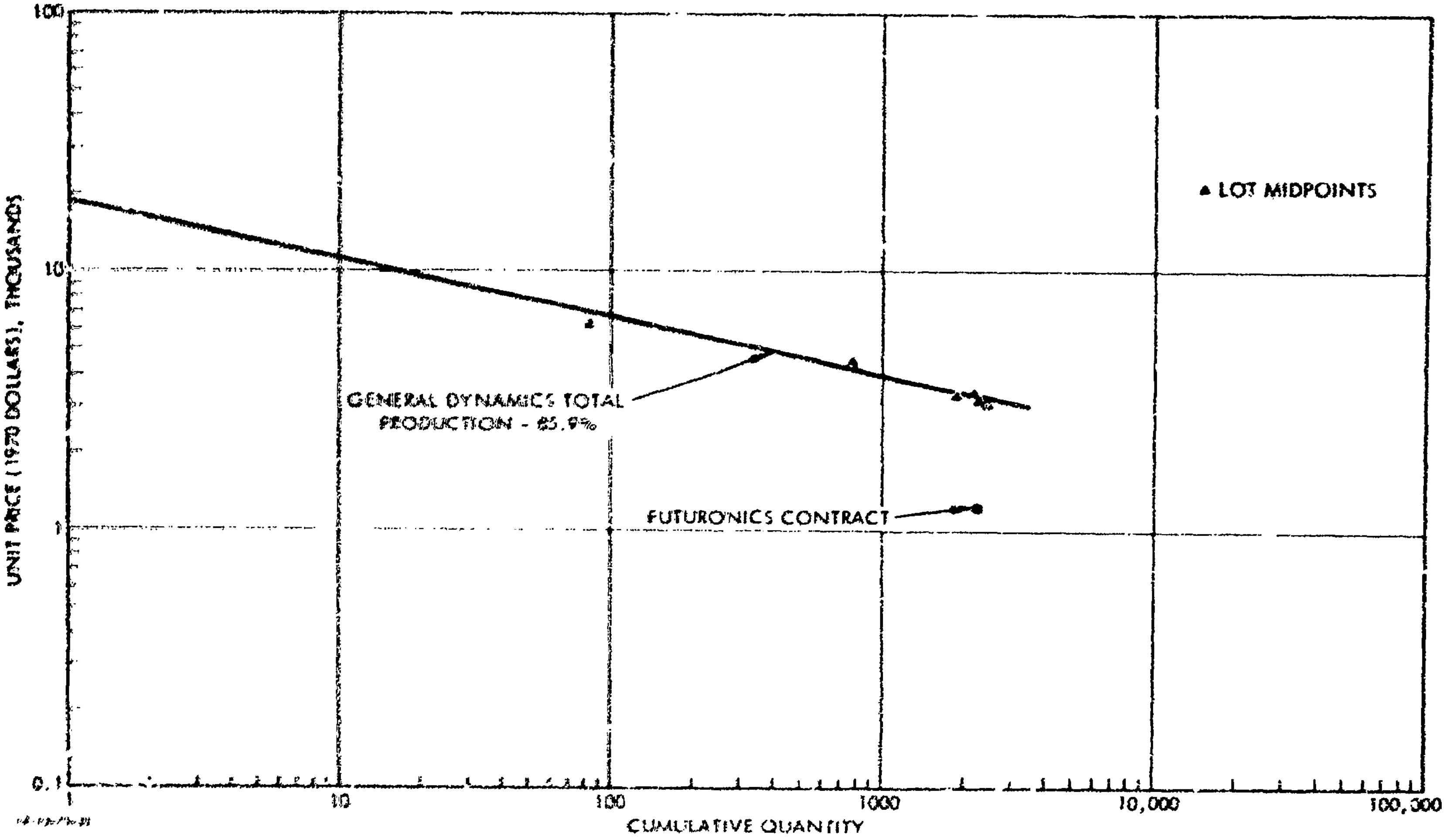


Figure H-17. PRICE-QUANTITY RELATIONSHIP FOR THE MD-522 MODULATOR-DEMODULATOR

Table H-18. PRICE-QUANTITY DATA FOR THE CV-1548 CONVERTER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Raytheon Corp.	65	Sole-source	560	7,692
	65	Sole-source	400	7,691
	65	Sole-source	69	4,833
	65	Sole-source	288	6,210
	65	Sole-source	408	5,967
	65	Sole-source	400	6,051
	69	Sole-source	1,820	3,702
Bowmar/ALI Company	69	Competitive	7,638	1,503

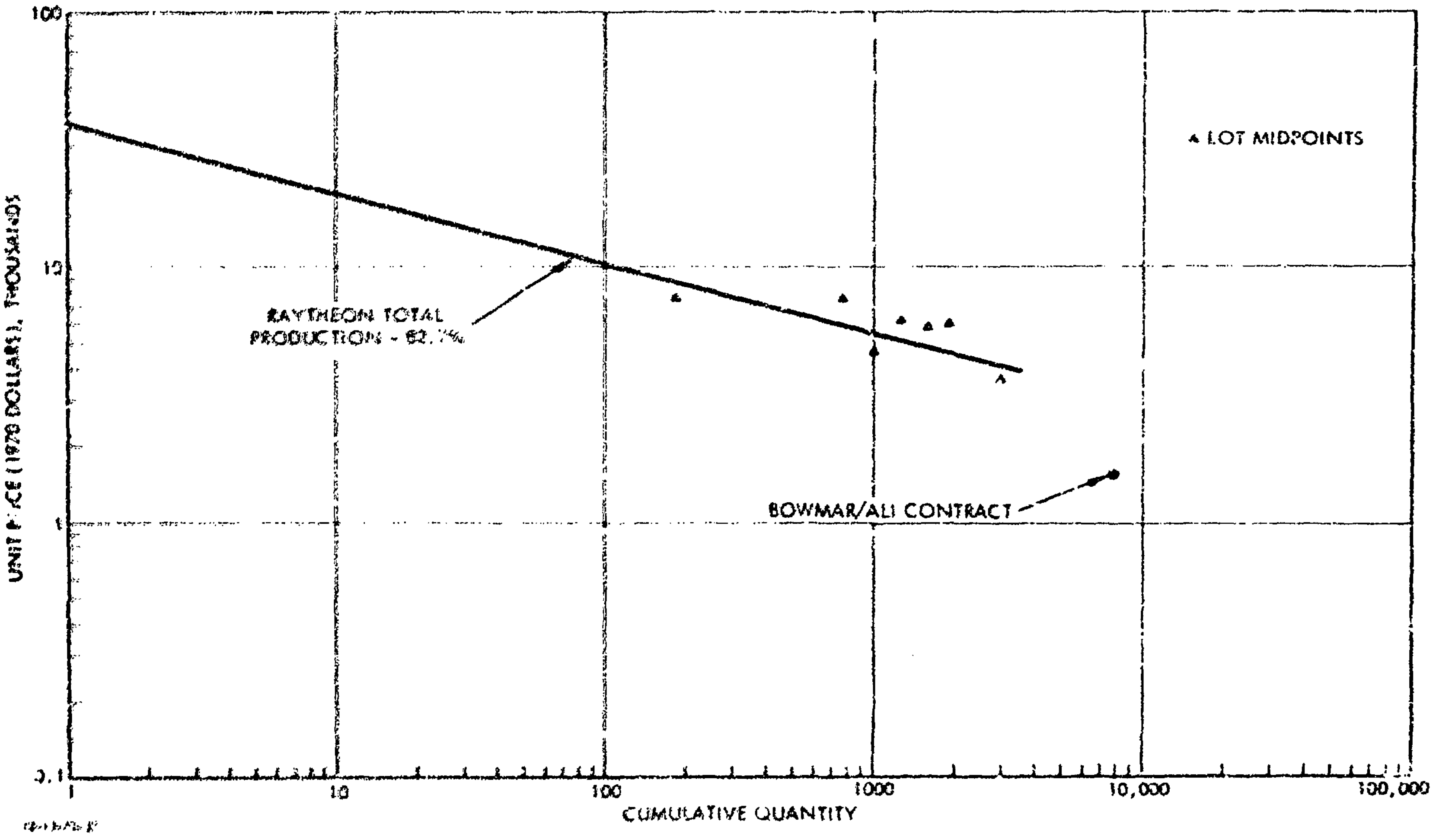


Figure H-18. PRICE-QUANTITY RELATIONSHIP FOR THE CV-1548 CONVERTER

C. DATA DROPPED FROM THE QUANTITATIVE ANALYSIS

There were four systems for which the price-quantity data initially seemed well suited for the type of quantitative analysis being done but which ultimately had to be dropped from the sample. These four were the SHRIKE Guidance and Control Unit, the M-14 Rifle, the WRC-1 Receiver-Transmitter, and the SIDEWINDER Guidance and Control Unit and Rolleron Assembly. Each of these four will be discussed in turn.

1. SHRIKE Guidance and Control Unit

The SHRIKE is an air-to-ground missile designed to home in on and destroy enemy radars. It is used by both the Air Force and the Navy, but the latter is the joint procuring agency. The Navy did the basic development of the SHRIKE, and in 1962 Texas Instruments (TI), Incorporated, won a competition to improve and complete the design and development of the guidance and control unit for the missile.

TI was paid $5,078,925 for this design and development work, and in FY 64 was paid $1,925,658 for additional R&D test models. The initial procurement plan for the SHRIKE G&C unit was approved in January 1963 and called for negotiated contracts with TI. In the Spring of 1964, the Navy decided to introduce competitive procurement for the G&C unit and devised a plan that called for a small part of the FY-65 requirement and most of the FY-66 requirement to be procured competitively. The contract negotiated with TI for the FY-65 production included options for FY 66 that would be exercised in the event that the winner of the competitive award failed to produce an acceptable missile.

The effect of competition is indicated by the fact that the unit price of the winning bid by Sperry Farragut was $4,770, although the negotiated unit price for the immediately preceding production by TI was $19,924. Although the influence of competition in reducing the unit price in this case seems manifest, the actual price-quantity data for the SHRIKE G&C unit could not be used in calculating the formula for the effect of competition, because the competitive prices were in too many cases negotiated upward--due to model changes. Thus, Sperry won the initial competition with a unit-price bid of $4,770 and actually produced 118 units at this price, but the bulk of the units produced under this first FY-65 contract (1,833 units) was at a unit price of $7,930 because of engineering changes introduced after the initial contract award. Engineering changes undoubtedly impacted to some degree on the price of all the items used in this analysis, but their effect in the case of the SHRIKE G&C unit seems so great as to make its prices incompatible with the others.

The data that were collected on the SHRIKE G&C units are displayed in Table H-19.

2. M-14 Rifle

Although the unit price of the M-14 Rifle did not come up to the criteria set for the quantitative analysis, the size and nature of the procurement and the obvious importance of the equipment to the Army made it a candidate for inclusion as an exception. After adoption by the Army, the first production contract was awarded sole-source to the Springfield Armory; and, subsequently, production contracts were given to three different civilian firms. The total program cost in excess of $136 million.

It developed, however, that the cost of the Springfield Armory production could not be determined, so there were no sole-source cost data--not even one point.

Since practically all the data obtained on the M-14 Rifle are contained in the report by U.S. Army Weapons Command, AMSWE-PPR-69-01, *Procurement History and Analysis of M-14 Rifle* (28 January 1969), it is not reproduced here.

Table H-19. PRICE-QUANTITY DATA FOR THE SHRIKE G&C UNIT

Contractor	FY	Quantity	Unit Price (1970 $)	Notes
Texas Instruments	63	75	29,772	Urgent requirement. "C" band. Negotiated.
	53	124	24,507	Pilot production. "S" band. Negotiated.
	65	294	6,340	"S" band. Negotiated.
	65	1,210	9,333	"S" band extended capability. Negotiated.
	65	204	6,105	"C" band. Negotiated.
	67	1,735	6,839	"S" band extended capability. Competitive. Split award.
	67	600	5,997	"S" band extended capability. Competitive.
	68	3,907	5,041	"S" band extended capability. Competitive. Split award.
	69	1,690	5,301	"S" band extended capability. Competitive.
	69	100	7,541	"C" band extended capability.
	70	300	7,499	"C" band extended capability.
	71	200	7,999	Unknown model. Competitive.
	72	100	9,020	Unknown model. Negotiated.
Sperry	65	118	5,600	"S" band. Competitive.
	55	1,833	9,310	"S" band extended capability. Competitive.
	67	1,936	5,999	"S" band extended capability. Competitive. Split award.
	67	448	6,110	"S" band extended capability.
	68	1,750	5,424	"S" band extended capability. Competitive. Split award.

3. WRC-1 Receiver-Transmitter

The WRC-1 is a receiver-transmitter used for ship-to-ship and ship-to-shore communications. It was first procured on a sole-source basis from the Bendix Corporation. The second procurement was competitive and was won by General Dynamics. Bendix regained the procurement on the subsequent and last competitive contract.

On the first contract, Bendix miscalculated its bid price and made a claim for $21 million to the government, and an award of $9 million was allowed. As a consequence, there is considerable uncertainty as to just what the correct unit price for the first Bendix production should be. Since this was the only sole-source buy and since there were only two additional contracts, the data were judged to be unsuitable for the quantitative analysis.

Table H-20 displays the data that were collected.

Table H-20. PRICE-QUANTITY DATA FOR THE WRC-1 RECEIVER-TRANSMITTER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Bendix	66	Sole-source	1,172	--*
	70	Competitive	84	15,557
	70	Competitive	45	14,839
	71	Competitive	7	14,201
	72	Competitive	32	13,593
General Dynamics	68	Competitive	240	14,981

*Unit price (1970 dollars) was (1) $8,560, if actual $9 million award is included, or (2) $12,086, if the claimed $21 million award is assumed.

4. SIDEWINDER: Guidance and Control Unit and Wing and Rolleron Assembly

The data collected on the Guidance and Control unit (G&C unit) and the wing and rolleron assembly were never seriously considered as being adequate for inclusion in the quantitative analysis sample, but the impact of competition seemed so striking that it was at first thought the data could be used some way in the analysis.

The only data available on the Guidance and Control unit were for three contracts in FY 71 and FY 72. However, since this particular G&C unit has been greatly modified from previous models, it is uncertain how much learning from prior production would be applicable even if the data were available.

The Raytheon Corporation had been producing the SIDEWINDER G&C unit under sole-source negotiations since the program's inception, but with this latest model in FY 71, the Navy decided to introduce a second producer and, to this end, asked for proposals from Philco-Ford and General Electric for a 700-unit production. Philco-Ford won the competition with a unit price bid of $6,100.

In FY 72, a sole-source contract was negotiated with Raytheon for 1,100 units at a unit price of $11,494. At the same time, an optional quantity of 470 units was proposed for competitive bidding between Raytheon and Philco-Ford, with quotes being asked for 100-unit incremental quantities from 100 to 500. The bids received are shown in Table H-21.

Philco-Ford won this competition, but because of an engineering change made after the above bids, both companies had to bid again on the 470 quantity. Again, Philco-Ford won, with a unit-price bid of $6,790. The losing Raytheon bid was for a unit price of $9,981.

The wing and rolleron assembly of the SIDEWINDER is four roughly triangular fins that are fitted on the aft third of

Table H-21. SIDEWINDER FY-72 OPTION QUANTITY BIDS

Quantity	Raytheon Unit Price	Philco-Ford Unit Price
100	$14,340	$5,875
200	13,296	5,800
300	13,188	5,785
400	12,783	5,770
500	12,486	5,760

the missile and are actuated to guide and stabilize it. They have an interior honeycomb structure, to give both strength and lightness. The Army CHAPARRAL uses two fins that are identical (except for the paint) to the SIDEWINDER's and two that are simple metal stampings. The Navy does the procurement for both services.

No specific procurement data prior to FY 70 were available; they were all in dead storage. However, the *Weapons Dictionary* indicates that about 37,525 SIDEWINDERs and 6,000 CHAPARRALs were produced through FY 69. This would mean that about 162,100 individual fins were made, all by the same company, Farmers Tool and Supply Corporation (FTS), before the current contract. The original price was $250 per fin (or $1,000 per SIDEWINDER set) and has gradually been reduced to the $199 point of the FTS bid for FY 70.

The Navy had from early in the program advertised the wing and rolleron procurements; but until FY 71, only FTS (the original supplier) had made bids. The data on the FTS FY-70 contract and the FY-71 low bid of Engineering Research, Inc. (ERI), are as follows:

FTS: FY 70 SIDEWINDER - 1,200 sets @$783.68 ($195.92 ea.)
CHAPARRAL - 3,030 sets @$397.66 ($198.83 ea.)
ERI: FY 71 SIDEWINDER - 1,400 sets @$698.00 ($174.50 ea.)
CHAPARRAL - 2,242 sets @$306.00 ($153.00 ea.)

Over the course of the production of about 162,100 fins, the unit price had declined from $250 to an average of $197.54 --about 21 percent. The first competitive buy resulted in a drop from the current price of 17 percent and from the original $250 of 34 percent.

D. DATA NOT SUITABLE FOR THE QUANTITATIVE ANALYSIS

In the attempt to collect as large a data base as possible, some cost histories were accumulated which were obviously not suited for the quantitative analysis. However, since the information was difficult to acquire, and since it does have a subjective bearing on the analysis, it is displayed here. The names of the 10 items in this category, grouped according to the primary reason the data could not be used, are listed below; and the data are displayed in Tables H-22 through H-31.

Aerno 42-0750 Voltage Regulator	*Unit price too low*
Aerno 42-2028 Generator	
AN/PRC-77 Manpack Radio Set	
AN/VRM-1 Radio Test Set	
Standard MR & ER Missiles	*No sole-source progress curve*
AN/SQS-208A Transducer	
AN/ARA-63 Radio Receiving-Decoding Set	
AN/ARC-54 Radio	*No competitive data*
AN/APM-123 Transponder Test Set	*Missing data*
AN/GRC-103 Radio Relay Set	

Table H-22. PRICE-QUANTITY DATA FOR THE AERNO 42-0750 VOLTAGE REGULATOR

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Bendix	66	Sole-source	380	135
	67	Sole-source	380	145
	68	Sole-source	295	134
	71	Competitive	298	54
	72	Competitive	164	55
Lear-Siegler	69	Competitive	344	75
	70	Competitive	314	71

Table H-23. PRICE-QUANTITY DATA FOR THE AERNO 42-2028 GENERATOR

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Bendix	67	Sole-source	380	769
	68	Sole-source	380	694
	68	Sole-source	273	465
Lear-Siegler	69	Competitive	332	512
	70	Competitive	314	427

Table H-24. PRICE-QUANTITY DATA FOR THE AN/PRC-77 MANPACK RADIO SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
RCA	67	Sole-source	7,837	1,171
	67	Sole-source	10,798	1,360
Electrospace Corp.	68	Competitive	56,312	668
	72	Competitive	4,133	433
E Systems, Inc.	70	Competitive	16,191	579
Cincinnati Electronics	73	Competitive	6,608	397
Sentinel Electronics	73	Competitive	6,617	397
Bristol Electronics	73	Competitive	451	530

Table H-25. PRICE-QUANTITY DATA FOR THE AN/VRM-1 RADIO TEST SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Monmouth Electric	67	Negotiated	188	624
Electrospace Corp.	68	Competitive	732	317
La Pointe Industries	69	Competitive	51	260
	70	Competitive	171	249

Table H-26. PRICE-QUANTITY DATA FOR STANDARD MR AND ER MISSILES

Contractor	Standard Missile	FY	Type Contract	Quantity	Unit Price (1970 $)
General Dynamics Corp.	MR	66	Sole-source	50	149,766
		67	Competitive	144	60,230
		67	Competitive	72	30,764
		68	Competitive	240	29,786
		69	Competitive	240	32,445
		70	Competitive	400	33,767
		71	Competitive	400	32,653
	ER	66	Sole-source	50	149,766
		67	Competitive	575	61,039
		67	Competitive	109	31,075
		68	Competitive	660	30,090
		69	Competitive	660	32,712
		70	Competitive	500	34,024
		71	Competitive	500	32,901

Table H-27. PRICE-QUANTITY DATA FOR THE AN/SQS-208A TRANSDUCER

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Dynamics Corp. of Amer.	67	Sole-source	29	76,869
Hazeltine Corp.	68	Competitive	54	40,508
	73	Competitive	69	30,621

Table H-28. PRICE-QUANTITY DATA FOR THE AN/ARA-63 RADIO RECEIVING-DECODING SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
AIL Company	69	Sole-source	1,325	7,849
ASC Systems Corp.	72	Competitive	1,067	2,882

Table H-29. PRICE-QUANTITY DATA FOR THE AN/ARC-54 RADIO

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Admiral Corp.	64	Sole-source	900	7,379
	64	Sole-source	853	5,796
	65	Sole-source	1,381	5,751
	66	Sole-source	1,160	5,076
	66	Sole-source	300	5,039
	65	Sole-source	3,103	4,866
	66	Sole-source	2,650	5,033

Table H-30. PRICE-QUANTITY DATA FOR THE AN/APM-123 TRANSPONDER TEST SET

Contract	FY	Type Contract	Quantity	Unit Price (1970 $)
Packard-Bell Company	63	Sole-source	6	2,143
	65	Sole-source	315	6,076
	67	Sole-source	625	6,034
	68	Sole-source	--*	--*
	69	Sole-source	195	6,629
	69	Sole-source	326	6,599
Tech Industries	69	Competitive	242	2,169
	71	Competitive	--*	--*

*Unknown.

Table H-31. PRICE-QUANTITY DATA FOR THE AN/GRC-103 RADIO RELAY SET

Contractor	FY	Type Contract	Quantity	Unit Price (1970 $)
Canadian Commercial	66	Sole-source	400	32,799
	68	Sole-source	350	25,771
Magnavox Company	69	Competitive	142	10,395
	69	Competitive	71	10,376

APPENDIX I

REVIEW OF DEFENSE INDUSTRY PROFIT STUDIES

Appendix I

REVIEW OF DEFENSE INDUSTRY PROFIT STUDIES

This appendix summarizes the results of various studies on defense industry profits. The empirical work of this report (Chapter IV) showed that large price reductions were obtained when competition was introduced into defense procurement through the use of formally advertised bidding. In order to get some indication of whether these price reductions were permitted by excessively high profits in the sole-source cases or by reductions in the costs of production, a review of defense profits was decided on. Although the data on profits of firms before and after formally advertised bidding are unavailable, the profits from negotiated and sole-source contracts should be the largest part of defense firms' profits, because these contracts are still for such a large proportion of the total procurements. Therefore, a study of defense industry profits will be, in effect, a study of profits from negotiated and sole-source procurements, which is the desired bias (since the possibility of excess profits on these contracts is being examined).

Since the studies reviewed below were made by government agencies and by academics, the approaches and specific areas emphasized vary somewhat. Because the allocation within a firm of profits, costs, and sales to military and commercial work is open to disagreement, the studies tried different ways of defining and separating defense from commercial profits. But in spite of the varied approaches, the overall results are that military profits are not significantly higher than commercial profits.

The *Defense Industry Profit Review: 1968 Profit Data* of the Logistics Management Institute (LMI) covers an 11-year period, 1958-1968, and includes all companies having over $200 million annual defense sales and a representative sample of companies whose annual defense sales are between $25 million and $200 million and have at least 10 percent of total company business in defense sales (43 companies for 1968). Sales, capital investment, and profits for these firms were allocated to defense work and to commercial work. The financial characteristics of these defense-oriented firms were compared with those of a sample of commercial companies that were in the same durable-goods categories.

The comparison of before-tax profit to sales ratios is shown in Table I-1. On the basis of Profits/Sales, defense business is less profitable than commercial business within the same firm and less profitable than predominantly commercial companies are. But a more important financial characteristic for investment decisions is the ratio of profits to total capital investment, where total capital investment is the amount assigned to capital shares and surplus plus long-term debt.

Table I-1. COMPARISON OF BEFORE-TAX PROFITS TO SALES

Type of Firm	Percentage (Profits/Sales)	
	1968	1967
Defense Companies		
Defense business	3.89	4.17
Commercial business	7.64	6.38
Commercial Companies	9.35	8.73

Source: LMI, p. 26.

Again, allocating the capital investment and profits within a defense-oriented company to its defense and commercial work, the ratios for profit to total capital investment (TCI) are shown in Table I-2. Depending on the year looked at, there may or may not be any difference between the defense and commercial profit rates within a firm, but the commercial companies again do better than the defense-oriented companies.

Table I-2. COMPARISON OF PROFITS TO TOTAL CAPITAL INVESTMENT--ALLOCATED

Type of Firm	Percentage (Profit/TCI)	
	1968	1967
Defense Companies		
Defense business	12.82	13.02
Commercial business	16.24	13.43
Commercial Companies	19.54	18.22

Source: LMI, p. 20.

Since there are problems in allocating profits within a firm, LMI also compared defense companies as a whole with commercial firms, using samples based on audited financial statements. The ratio (found by LMI) of profits to total capital investment on this sample is shown in Table I-3. These figures show that in 1967 there was little difference between the profits of defense and commercial companies, but a larger difference existed in 1968.

A comparison of the above figures with the results given in Table I-2 for the same Profit/TCI ratio shows differences that could lead to different policy recommendations. The differences in the ratios are attributable to two factors: (1) Table I-2 used contractor-supplied data for defense firms, while the second used published financial data; and (2) the

Table I-3. COMPARISON OF PROFITS TO TOTAL CAPITAL INVESTMENT--NON-ALLOCATED

Type of Firm	Percentage (Profit/TCI)	
	1968	1967
Defense-oriented companies	16.2	16.0
Commercially-oriented companies	21.7	17.5

Source: LMI, p. 46

data for the commercial firms were based on different sizes of samples for the two tables. Because the financial ratios are so sensitive to the data base used, care must be taken in statting conclusions about defense profits. Therefore, other studies of defense industry profits will be reviewed in order to obtain a general consensus.

Another study with an approach similar to LMI's was done by the General Accounting Office (GAO) during 1970. GAO studied the profits on negotiated contracts for 74 large DoD contractors and required them to separate the sales, profits, and investments for the defense and commercial portions of their sales. (Note that the samples of the GAO and LMI studies differ, but that both separate defense from commercial business within a firm.) For its findings and conclusions, the report states:

> .. profits on DOD contracts averaged 4.3 percent of sales over the 4 years, 1966 through 1969, but profits on comparable commercial work of the 74 contractors averaged 9.9 percent of sales for the same period. When profit was considered as a percent of the total capital investment (total liabilities and equity but exclusive of Government capital) used in generating the sales, the difference narrowed--11.2 percent for DOD sales and 14 percent for commercial sales. Further, when profit was considered as a percent of equity capital investment of stockholders, there was little difference between the rate of re-

> turn for defense work and that for commercial work. The 74 large DOD contractors realized average returns before Federal income taxes of 21.1 percent on equity capital allocation to defense sales and 22.9 percent on equity capital allocated to commercial sales....
>
> The major factor causing the rates of return on contractor capital investment for defense and commercial work to be similar was the substantial amount of capital provided by the Government in the form of progress payments, cost reimbursements, equipment, and facilities. This reduced the capital investment required from the contractors for defense work. [28, p. 1]

Thus, the GAO and LMI studies report the same general ranges for the various financial ratios in spite of their different data bases. Moreover, GAO feels that the rates of return on defense and commercial work are quite similar when the amount of government-provided capital is taken into account.

A. M. Agapos and Lowell E. Gallaway, in their article "Defense Profits and the Renegotiation Board in the Aerospace Industry" [65], attempt to evaluate empirically the effectiveness of the Renegotiation Board established to insure that contractors with the government do not reap unusual profits from their activities. The study covers the period 1942-67 and looks at aerospace firms that are government prime contractors, dividing the firms into two groups--(1) those with 80 percent or more of their sales subject to renegotiation and (2) those with less than 80 percent of their sales subject to renegotiation, but with 50-80 percent of their total sales to the government. Using multiple least-squares regression techniques, they estimated a statistical profit function for the U.S. aerospace industry. The measures of profitability used were profits (both before and after taxes and renegotiation) as a fraction of net worth and as a fraction of total assets. (The Renegotiation Act of 1951 instructs the Renegotiation Board to consider the return to net worth in its determinations.) Agapos and Gallaway report that their regression results suggest "that the presence of the board has led to an inflation of aerospace profits which have been renegotiated away by the board" [65, p. 1103]. Their overall basic conclusions are as follows:

> 1. There is almost no evidence that aerospace firms in contemporary America are able to reap unusually large or excessive profits from the presence of positive shifts in the demand for military hardware. 2. It appears that the parties to the contract negotiation process--an integral part of defense procurement in the aerospace industry--have very effectively discounted the presence of the Renegotiation Board and have thus rendered it quite ineffectual. [65, pp. 1103-4]

George J. Stigler and Claire Friedland, in their article "Profits of Defense Contractors" [66], use a different approach to a profits study by looking at the profitability of investments made in defense contractors. They feel that "Stock market experience avoids (or at least ignores!) the complications of accounting practices, including the difficulties of segregating assets and income within the enterprise" [66, p. 692]. They looked at the largest defense prime contractors from the annual DoD lists, compared the contracts with the total sales of the companies in the same years to obtain an average percentage of defense business, and calculated the market value of an initial investment in common stock of a company with reinvestment of all dividends in the stock of that company. The investment performance of the defense firms was compared with the average value of an investment in each company listed on the New York Stock Exchange. Their main findings are as follows:

> 1. The investments in defense contractors were almost twice as profitable in the 1950's as the investment in all listed stocks....2. In the 1960's the investments in defense contractors did approximately as well as in all NYSE stocks....Thus there is substantial agreement between our study and that of the Logistics Management Institute. [66, p. 693]

But in spite of their results, Stigler and Friedland are hesitant to judge the efficiency of present systems of procurement.

They suggest that more important questions are the risk in the defense area, the existence of monopoly or blocked entry into the defense contracting business, and the relationship between the profits of defense contractors and their performance on contracts.

Another study, Douglas R. Bohi's "Profit Performance in the Defense Industry," examines the

> profit performance of defense industry firms in the past decade to determine whether the profit rates of firms engaged heavily in defense contracting differ significantly from profit rates of non-defense-oriented firms. Related points of interest to be considered include: (1) whether there is any relationship between the percentage of business attributed to defense contracts and the profit performance of different firms, (2) whether traditional defense industry firms have become more or less dependent on defense business, and (3) whether the Vietnam war has altered the profit performance of defense firms. [67, p. 721]

Bohi looks at a sample of 36 defense firms that consistently appeared on the annual lists of the largest defense contractors for the period 1960 through 1969. He examines the volume of defense contracts awarded to the 36 firms; defense profits as a percentage of total sales; profits; and profits as a percentage of net worth (the latter ratio is the only measure in common with several other studies). He was unable to find significant differences between the profit rates of the defense firms and those of the 500 largest manufacturers as listed in *Fortune* for the same period. He further found that the "hypothesis of no significant correlation between profits and the concentration of defense business cannot be rejected" [67, p. 726]. Bohi also reports that the traditional defense contractors have been diversifying into commercial business, because the ratio of defense contracts to sales had declined (while the total defense contracts to these firms had not declined). He also finds that traditional defense firms (the 36 that have been consistently on the list of the largest contractors for the period 1960 through 1969) have been taking a smaller portion of total defense procurement. In considering the issue of whether there has been a change in defense profits as a result of the Vietnam war, he notes that profits and profit rates for the 36 defense firms studied did increase during the Vietnam war period, but that so did manufacturing profits in general, and that the increases are not significantly different. "In fact, it appears that the source of the bulk of the increase in profits of defense contractors during the war was nondefense business" [67, p. 727]. Bohi concludes that

> there is no evidence for arguing that defense business is any more or less profitable than nondefense business in general. Whether or not this result implies that defense profits are too high or too low depends, of course, on the relative risk and relative efficiency of defense and nondefense business....Relative risk and relative efficiency, not relative profit performance, are the important issues. [67, p. 728]

To summarize all these studies of defense industry profits, it appears to be still uncertain as to whether or not defense industry profits (either for the defense contractor as a whole or for just the defense part of the business) are significantly lower than profits for commercially-oriented firms. Some studies (e.g., Stigler and Bohi) have reported no statistically significant difference, while the LMI and GAO studies report that some measures of profits give lower returns on defense business and for defense-oriented firms. But in either case, all studies have suggested that the important question for policy purposes is not the level of profits but their adequacy--including consideration of government-supplied capital and the risk borne by the firms.

Recalling the initial purpose of this review of defense industry profits, there is no strong evidence that the defense industry is excessively profitable. In fact, since the profit rate is lower on defense business in some of the studies, other factors (like government-supplied capital and the firm's cost risk) would have to have a large impact to make defense profits higher than commercial rates. Since defense profit rates do not appear to be excessively high, the price reductions obtained under competitive, formally advertised procurements are likely to have been enabled by reductions in the production cost.

APPENDIX J

DETAILED COMPARISON OF COMMERCIAL AND MILITARY AIRCRAFT, SHIP, AND WHEELED-VEHICLE PRICES

CONTENTS

Appendix J

DETAILED COMPARISON OF COMMERCIAL AND MILITARY AIRCRAFT, SHIP, AND WHEELED-VEHICLE PRICES

Chapter V presented the methodology used in making the comparison of military and commercial prices and some summary tables of the results. This appendix presents the data and detailed calculations that were used to derive the summary tables of Chapter V.

A. COMPARISON OF MILITARY AND COMMERCIAL AIRCRAFT

Table J-1 presents the airframe cost index used to normalize prices to 1970 dollars.

Table J-1. AIRFRAME COST INDEX

Year	Index	Year	Index	Year	Index
1945	1.586	1955	1.388	1965	1.225
1946	1.566	1956	1.370	1966	1.170
1947	1.546	1957	1.352	1967	1.132
1948	1.526	1958	1.335	1968	1.006
1949	1.506	1959	1.318	1969	1.041
1950	1.486	1960	1.285	1970	1.000
1951	1.466	1961	1.270	1971	.972
1952	1.446	1962	1.270	1972	.939
1953	1.426	1963	1.270		
1954	1.407	1964	1.254		

Source: Office of the Assistant Secretary of Defense (Systems Analysis)

1. Piston Aircraft - Case Studies

a. C-119 Versus Convair 240, 340, 440

The tables for commercial aircraft are set up with nine column headings (see Table J-2). The first four are self-explanatory. The fifth column (labeled "Empty Weight Delivered") is the product of the number of planes delivered that year and the empty weight of one airplane. The sixth column is the product of the number of planes delivered that year and the useful load-carrying capacity (hereinafter shortened to "useful capacity") of one airplane. The seventh column is the selling price or average selling price of one plane in that year (or current-year dollars). The eighth column is the (seventh-column) selling price normalized to 1970 dollars, using the conversion indices of Table J-1. The last column is the total price--obtained by multiplying the price per plane (in 1970 dollars) by the number of planes delivered that year. This total price should be roughly the amount received by the aircraft manufacturer for total flyaway sales of that plane in that year. The totals at the bottom are the total number of planes delivered, total empty weight delivered, total useful capacity delivered, and total program sales over the span of years the plane was produced.

As Table J-2 indicates, the total amount received by Convair for its 240, 340, 440 series was $454,590,000 (1970 dollars) for a total of 565 planes delivered. Total sales of the Convair series are then divided by total empty weight delivered, to obtain a price per pound for that particular commercial plane. Since total pounds delivered was 16,498,000, the average price per pound of empty weight for the Convair 240, 340, 440 was $27.55. Price per pound on a useful-capacity basis was $48.98.

Data for the C-119 program are shown in Table J-3. In this case, more military planes were produced than commercial planes. In order to normalize for quantity, the quantity of C-119s pro-

Table J-2. CONVAIR 240, 340, 440 PROGRAM DATA

Year(s)	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity[a] Delivered (thousand pounds)	Price (million current $)	Price (million 1970 $)	Total Price (million 1970 $)
1947-1951	240	27.0[b]	176	4,752	2,351	.440[c]	.66	116.16
1952	340	29.5	35	1,033	613	.541	.78	27.30
1953	340	29.5	101	2,980	1,769	.578	.82	82.82
1954	340	29.5	61	1,800	1,069	.613	.86	52.46
1955	340	29.5	14	413	245	.750	1.04	14.56
1956	440	31.3	57	1,784	1,048	.660	.89	50.73
1957	440	31.3	79	2,473	1,452	.670	.91	71.89
1958	440	31.3	21	657	386	.700	.93	19.53
1959	440	31.3	14	438	258	.768	1.01	14.14
1960	440	33.5	5	168	92	.780	1.00	5.00
Total			563	16,498	9,282			454.59

[a] Here defined (for Tables J-2 through J-17) as aircraft maximum gross takeoff weight minus empty weight.

[b] Average weight for the five-year span.

[c] Average price for the five-year span.

duced is cut off to equal the total production quantity (563 aircraft) of the Convair 240, 340, 440. The total cost of 563 C-119s is $627,230,000 (RDT&E plus procurement) and must be increased by 4.6 percent to account for government capital investment. Thus, the total program cost is $646,080,000 (1970 dollars). This total is divided by total empty weight delivered on 563 planes (22,520,000 pounds), to arrive at a price of $29.13 per pound of empty weight for the C-119. Similarly, the price per pound on a useful-capacity basis was $40.54.

Finally, the ratio of the price per pound of the military aircraft to the price per pound of the commercial aircraft is used as a comparison of the costs. The price per pound of empty weight for the C-119 as compared to the price per pound of empty weight for the Convair series ($29.13/$27.55) gives a ratio of 1.06. The C-119 cost about 6 percent more per pound; the two programs are quite comparable. Likewise, the ratio on a useful-capacity basis ($40.54/$48.98) is 0.83.

Table J-3. C-119 PROGRAM DATA (1948-1951)

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Procurement Cost (million current $)[a]	RDT&E and Procurement Cost (million 1970 $)[b]
1948	C-119C	40	37	1,480	1,064	26.71	40.76
1949	C-119G	40	99	3,960	2,846	43.07	64.86
1950	C-119C	40	53	2,120	1,523	24.17	35.93
1951	C-119C,F,G,H /R4Q-1	40	438[c]	17,520	12,586	335.60[c]	491.99[c]

[a] Flyaway costs only.

[b] Estimated RDT&E of 50 times the cumulative average cost of 100 units. 50 x .932 = 46.60.

[c] Unit price in 1951 assumed in subsequent case studies:
For Convair series, analysis for 374 of these 438
For Lockheed Constellation, analysis for 336 of these 438
For DC-6, analysis for 348 of these 438
For DC-7, analysis for 147 of these 438.

b. C-119 Versus Lockheed Constellation

Lockheed received $1,096,970,000 (1970 dollars) in sales of its Constellation series (Table J-4). The total empty weight delivered for 519 airplanes was 34,771,000 pounds. Thus, the price per pound of empty weight for the Constellation was $31.55. The price per pound on a useful-capacity basis was $41.24.

The total cost for 519 C-119s is $575,570,000 (Table J-3). To account for government capital investment, this figure is increased by 4.6 percent, for a total of $602,050,000. Total empty weight delivered on 519 planes is 20,760,000 pounds, for a price of $29.00 per pound of empty weight for the C-119. (Similarly, the total useful capacity delivered on 519 planes is 14,918,655 pounds--giving a price per pound of useful capacity of $40.36.) Comparison of this $29.00 price to the price of $31.55 per pound of empty weight for the Constellation series produces a ratio of 0.92. The two planes are comparable in price, the C-119 costing about 8 percent less per pound. (On the basis of useful capacity, price-per-pound comparison of the C-119 and the Constellation series produces a ratio of 0.98--i.e., the C-119 cost 2 percent less per pound.)

Table J-4. LOCKHEED CONSTELLATION SERIES PROGRAM DATA

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Price (million current $)	Price (million 1970 $)	Total Price (million 1970 $)
1945	049	58.0[a]	10	580	420	.684	1.085	10.85
1946	049	56.0[a]	57	3,306	2,394	.725[b]	1.135	64.70
1947	049 649 749	58.0[a]	6 14 35	3,190	252 590 1,474	.790 .760 .870	1.221 1.175 1.345	70.85[c]
1948	749	58.0[a]	22	1,276	938	.930[b]	1.419	31.22
1949	749	57.0[a]	17	969	725	1.080	1.626	27.64
1950	649 749	57.0[a]	3 32	1,995	128 1,364	.897 1.022[b]	1.333 1.519	52.61[c]
1951	649 749 1049	57.0[a] 69.0	2 18 4	1,416[c]	85 767 204	.899 1.120 1.250	1.319 1.642 1.833	39.52[c]
1952	1049	69.0	20	1,380	1,020	1.260[b]	1.822	36.44
1953	1049C,D,E,G	69.0	28	1,932	1,428	1.500[b]	2.139	59.89
1954	1049C,D,E,G	69.0	41	2,829	2,091	1.700	2.392	98.07
1955	1049C,D,E,G	69.0	55	3,795	3,520	2.015[b]	2.797	153.84
1956	1049C,D,E,G 1049H	69.0	40 3	3,657	2,560 192	2.110[b] 2.070	2.891 2.836	124.15[c]
1957	1049C,D,E,G 1049H 1649	69.0 85.3	15 27 35	5,084[c]	960 1,728 1,670	2.180 1.906 2.500	2.947 2.577 3.380	232.08[c]
1958	1049C,D,E,G 1049H 1649	69.0 85.3	3 19 9	2,286[c]	192 1,216 429	2.200 1.893 2.356	2.937 2.527 3.145	85.13[c]
1959	1049H	69.0	4	276	256	1.893	2.495	9.98
Total			519	34,771	26,603			1,096.97

[a] Average weight.

[b] Average price.

[c] Where weights and prices vary among models, empty weight delivered and total price have been prorated according to the amount produced of each model.

c. C-119 Versus DC-6

For the 537 DC-6s sold (Table J-5), Douglas received a total of $791,630,000. The total empty weight delivered was 28,258,000 pounds. On a price-per-pound basis, the DC-6 cost $28.11. On a useful-capacity basis, the total pounds delivered was 26,275,023--giving $30.13 per pound.

The cost of the first 537 (total number of DC-6s built) C-119s was $596,700,000 (Table J-3). It is increased by 4.6 percent, for a total of $624,100,000. Total empty weight delivered for 537 planes was 21,480,000 pounds; total useful

Table J-5. DC-6 PROGRAM DATA

Year(s)	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Price (million current $)	Price (million 1970 $)	Total Price (million 1970 $)
1947-1949	DC-6	51.5	150	7,725	6,856	.69[a]	1.05	157.50
1950-1952	DC-6,A,B	52.8[b]	114	6,019	5,720	.97[a]	1.42	161.88
1953	DC-6,A,B	52.8[b]	69	3,643	3,462	1.10	1.57	108.33
1954	DC-6,A,B	52.8[b]	41	2,165	2,057	1.20	1.69	69.29
1955	DC-6,A,B	52.8[b]	14	739	703	1.25	1.74	24.36
1956	DC-6,A,B	52.8[b]	39	2,059	1,957	1.30	1.78	69.42
1957	DC-6,A,B	52.8[b]	44	2,323	2,208	1.30	1.76	77.44
1958	DC-6,A,B	52.8[b]	65	3,432	3,262	1.40	1.87	121.55
1959	DC-6,A,B	52.8[b]	1	53	50	1.40	1.86	1.86
Total			537	28,158	26,275			791.63

[a] Average price for the three-year span.

[b] Average weight for the various models.

capacity, 15,436,065 pounds. The price per pound of empty weight for the C-119 was $29.06; the price per pound of useful capacity, $40.43. The ratio of the C-119 price per pound of empty weight to the DC-6 price per pound of empty weight is 1.03. The two are very close in price per pound of empty weight. However, on a useful-capacity basis, the ratio of the C-119 price per pound to the DC-6 price per pound is 1.34--indicating that the DC-6 cost about 34 percent more.

d. C-119 Versus DC-7

A total of 336 DC-7s was delivered, for a total of $1,032,110,000 (1970 dollars) paid to Douglas (Table J-6). The total empty weight of the DC-7s was 23,154,000 pounds; total useful capacity, 17,865,509 pounds. On a basis of price per pound of empty weight, the DC-7 cost $44.58, on a basis of price per pound of useful capacity, $57.77.

In order to compare the C-119 and the DC-7, we will find the cost of the first 336 planes (Table J-3). The total RDT&E and procurement cost must be increased by 4.6 percent to account

Table J-6. DC-7 PROGRAM DATA

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Price (million current $)	Price (million 1970 $)	Total Price (million 1970 $)
1953	DC-7	66.3	11	729	615	1.60	2.28	25.08
1954	DC-7,B,C	69.0[a]	48	3,312	2,548	1.93[b]	2.72	130.56
1955	DC-7,B,C	69.0[a]	30	2,070	1,592	2.07[b]	2.87	86.56
1956	DC-7,B,C	69.0[a]	67	4,623	3,555	2.25[b]	3.08	206.36
1957	DC-7,B,C	69.0[a]	123	8,487	6,529	2.32[b]	3.14	386.22
1958	DC-7,B,C	69.0[a]	57	3,933	3,026	2.60	3.47	197.79
Total			336	23,154	17,866			1,032.11

[a] Average weight.
[b] Average price.

for investment of government capital. The total program cost for 336 C-119s is $377,323,580. Total empty weight delivered came to 13,440,000 pounds; total useful capacity, 9,658,320 pounds. The price of the C-119 is then $28.07 per pound of empty weight and $39.07 per pound of useful capacity. The ratio of the C-119 price per pound of empty weight to that of the DC-7 ($28.07/$44.58) was 0.63. It appears that the price per pound of empty weight for the C-119 was about 37 percent less than that of the DC-7. On a basis of useful capacity, the ratio of the C-119 price per pound to that of the DC-7 ($39.07/$57.77) was 0.68--indicating that the price per pound of the C-119 was about 32 percent less than that of the DC-7.

a. C-123 Versus Convair 240, 340, 440

When comparing commercial and military programs in which more commercial planes were produced than military planes, we must use another method. To estimate projected costs of the military aircraft (C-123), a least-squares regression line was fitted through actual cost points. A progress curve was then drawn of the cumulative average cost versus cumulative quantity. The C-123 program is shown in Table J-7, and its progress curve is given in Figure J-1. Since only 472 C-123s were produced, the progress curve of Figure J-1 was extended to a production quantity of 563 planes (total number of 240s, 340s, and 440s built). Developed on a cumulative-average basis, the curve determined that through unit 563 the cumulative average flyaway cost would have been $865,000. The RDT&E spent on the program was estimated as 50 times the cumulative average cost of 100 units. Since the progress curve shows cumulative average cost to be $1,220,000, the RDT&E would be $61 million. The cost for the entire program through 563 planes would be (RDT&E plus procurement) as follows:

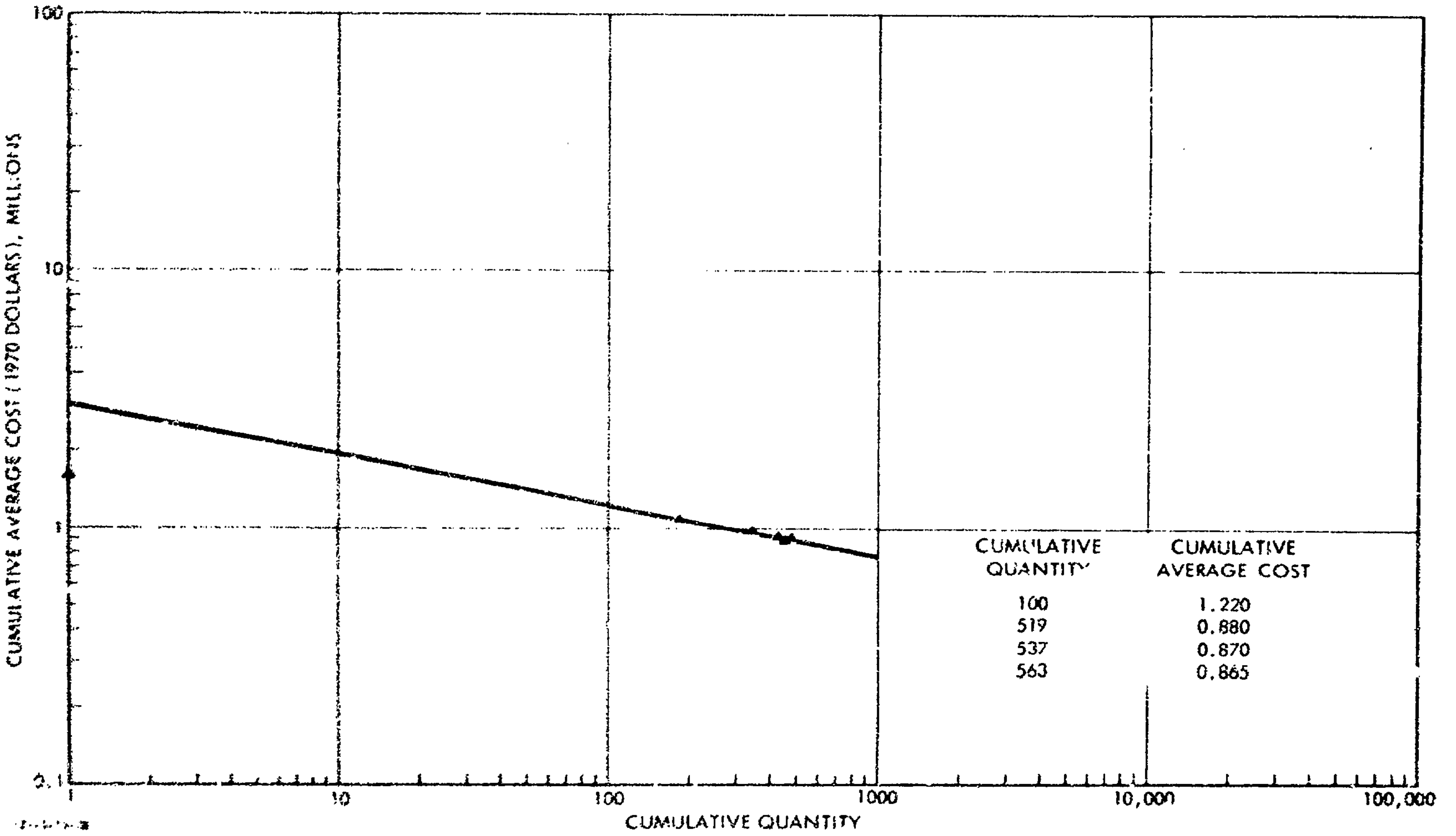
RDT&E	$ 61,000,000
Procurement (563 x $865,000)	+ 486,995,000
	$547,995,000
Return on government investment	x 1.046
	=$573,202,770

Table J-7. C-123 PROGRAM DATA[a]

Year	Number Delivered	Unit Flyaway Cost (million 1970 $)
1952	1	1.62
1953	186	1.09
1954	164[b]	0.82
1955	73	0.66
1956	42	0.82
1957	6	0.73
Total	472	

[a] Average empty weight: 31,050 pounds; average useful capacity: 26,950 pounds; RDT&E estimate: $61 million (1970 dollars).

[b] For comparison with DC-7, "number delivered" ended here with 149 of these 164. Unit price in 1954 is assumed.



CUMULATIVE QUANTITY	CUMULATIVE AVERAGE COST
100	1.220
519	0.880
537	0.870
563	0.865

Figure J-1. C-123 PROGRESS CURVE

The program cost is increased by 4.6 percent to account for government capital investment. This cost is divided by total pounds (empty weight of one plane times 563 planes) to give the price per pound of empty weight to the military. The empty weight of the C-123 is 31,050 pounds. If 563 planes had been built, the total empty weight delivered would have been 17,481,150 pounds. Thus, the price per pound of empty weight for the C-123 was $32.79. The price per pound of useful capacity was derived similarly: 563 x 26,950 pounds = 15,172,850 pounds of useful capacity; thus, the price per pound of useful capacity was $37.78.

The previously derived price per pound of empty weight for the Convair 240, 340, 440 was $27.55; price per pound of useful capacity, $48.98 (see Table J-2). On an empty-weight basis, the ratio of the military C-123 to the commercial Convair series is 1.19 (the C-123 cost 19 percent more per pound); on a useful-capacity basis, the ratio is 0.77 (the C-123 cost 23 percent less per pound).

f. C-123 Versus Lockheed Constellation Series

From the C-123 progress curve (Figure J-1), we see that had 519 (the number of Constellations built) C-123s been built, the cumulative average flyaway cost of the 519 planes would have been $880,000 (1970 dollars). The total procurement cost would then be $456,720,000. The estimated RDT&E cost was $61 million. The cost of the program projected through 519 units would then be the sum of the RDT&E and procurement: $517,720,000. This amount must be increased by 4.6 percent, so that the total cost to the military for 519 C-123s would be $541,500,000. Total empty weight delivered would be 16,110,000 pounds; total useful capacity, 13,878,762 pounds. The cost of the C-123 is $33.60 per pound of empty weight and $39.02 per pound of useful capacity. The Constellation cost $31.55 per pound of empty weight and

$41.24 per pound of useful capacity (see Table J-4). The ratio of the C-123 price per pound of empty weight to the Constellation price per pound of empty weight is 1.06. On a basis of useful capacity, the ratio of the C-123 price per pound to the Constellation price per pound is 0.95.

g. C-123 Versus DC-6

From the C-123 progress curve (Figure J-1), we note that for 537 planes (the number of DC-6s built) the cumulative average flyaway cost is $870,000. Thus, for a total of 537 planes, the procurement cost would have been $467,190,000. Estimated RDT&E spent on the program was $61 million, for a program cost of $528,190,000. Since this figure must be increased by 4.6 percent to account for government-provided capital, 537 C-123s cost a total of $552,500,000. Total empty weight delivered on 537 planes is 16,670,000 pounds; total useful capacity, 14,322,174 pounds. Thus, the C-123 cost $33.13 per pound of empty weight and $38.58 per pound of useful capacity. The DC-6 cost $28.11 per pound of empty weight and $30.13 per pound of useful capacity (see Table J-5). Comparing the military and the civilian plane on bases of empty weight and useful capacity yields ratios of 1.18 and 1.28, respectively. The C-123 cost about 18 percent more per pound of empty weight than the DC-6 and about 28 percent more per pound of useful capacity.

h. C-123 Versus DC-7

Since more DC-7s were built than C-123s, it was not necessary to project beyond the actual number of C-123s that were built. The procurement and RDT&E for 336 C-123s was $387,720,000 in 1970 dollars (see Table J-7). To account for government capital investment, this figure is increased by 4.6 percent, to $405,600,000. Total empty weight delivered of 336 aircraft is 10,420,000 pounds; total useful capacity, 9,324,000 pounds.

Thus, the C-123 cost $38.94 per pound of empty weight and $43.50 per pound of useful capacity. For comparison, the DC-7 cost $44.58 per pound of empty weight and $57.77 per pound of useful capacity (see Table J-6). On bases of empty weight and useful capacity, military and civilian plane comparisons yield ratios of 0.87 ($38.94/$44.58) and 0.75 ($43.50/$57.77); the C-123 cost roughly 13 percent less per pound of empty weight than the DC-7 and 25 percent less per pound of useful capacity.

i. C-124 Versus Convair 240, 340, 440

The procurement figures for the C-124 are shown in Table J-8, and its calculated progress curve is presented in Figure J-2.

Table J-8. C-124 PROGRAM DATA[a]

Year	Model	Number Delivered	Unit Flyaway Cost (million 1970 $)
1949	C-124A	28	3.31
1950	C-124A	50	1.88
1951	C-124A,C	165	2.76
1952	C-124C	151[b]	2.30
1953	C-124C	52	2.33
Total		446	

[a] Average empty weight: 101,165 pounds; average useful capacity: 115,235 pounds; RDT&E estimate: $132 million (1970 dollars).

[b] For comparison with DC-7, "number delivered" ended here with 93 of these 151. Unit price in 1952 is assumed.

From the progress curve (Figure J-2), we see that the cumulative average cost of 100 C-124s is $2,640,000. Thus, the RDT&E cost is estimated to be 50 x $2,640,000, or $132 million. Had 563

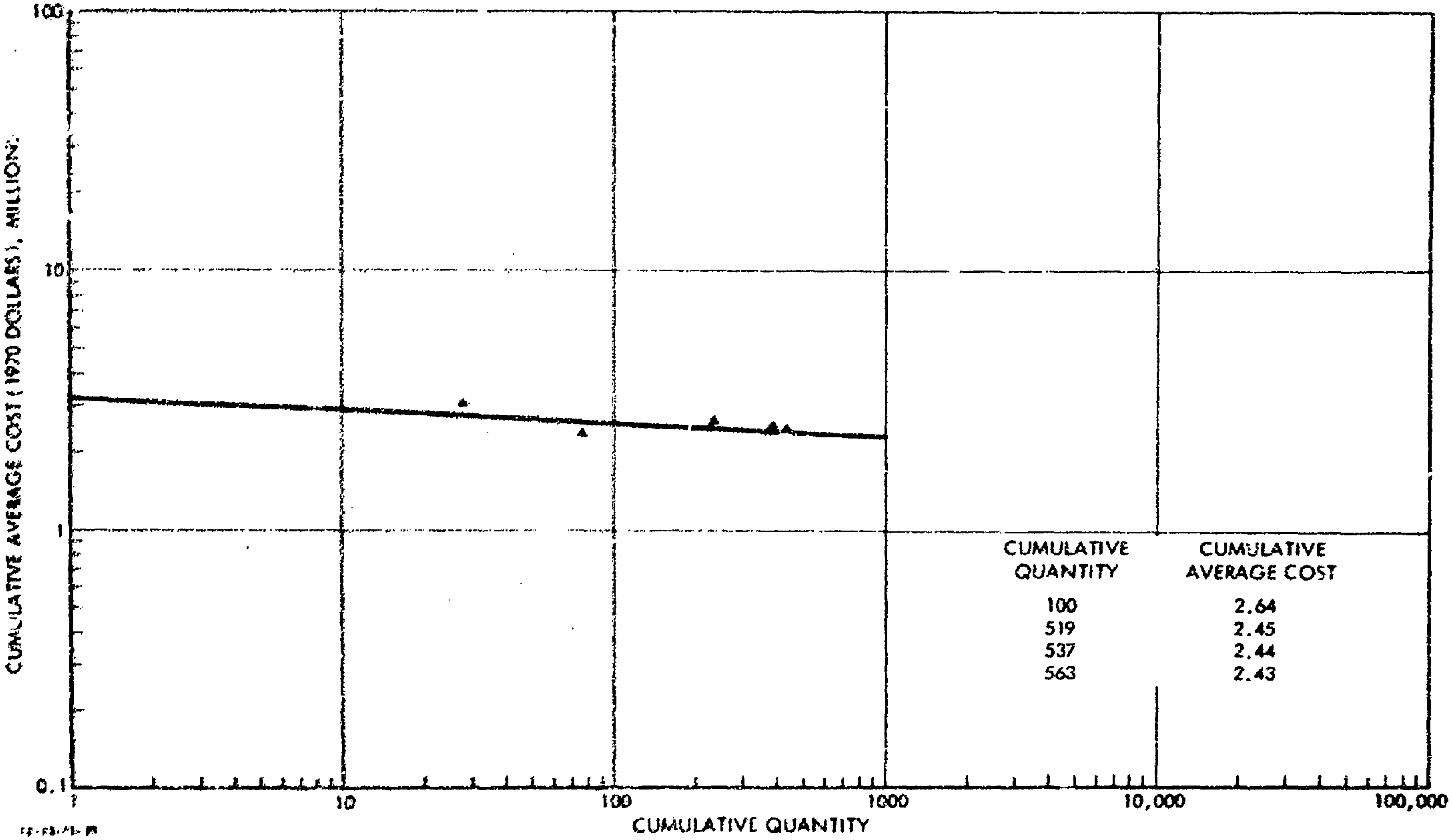


FIGURE J-2. C-124 PROGRESS CURVE

(the total number of 240s, 340s, and 440s) planes been built, the cumulative average flyaway cost would have been $2,430,000 (Figure J-2). The procurement cost for 563 aircraft is $2,430,000 x 563, or $1,368,090,000. The total program cost is $1,500,090,000 (RDT&E + procurement). This total must now be increased by 4.6 percent to account for government-provided capital, for a total of $1,569 million. Total empty weight delivered for 563 aircraft was 56,960,000 pounds; total useful capacity, 64,877,305 pounds. The cost per pound of empty weight for the C-124 was $27.55; the cost per pound of useful capacity, $24.18. The Convair 240, 340, 440 also cost $27.55 per pound of empty weight, but $48.98 per pound of useful capacity (see Table J-2). The two planes are equal in price per pound of empty weight; but, on a basis of useful capacity, the C-124 cost 51 percent less than the Convair 240, 340, 440 in price per pound.

j. C-124 Versus Lockheed Constellation

The RDT&E cost of the C-124 is estimated to be $132 million. In projecting the progress curve (Figure J-2) to unit 519 (total number of Constellations built), we see that the cumulative average cost of 519 aircraft is $2,450,000. Thus, the procurement cost for production of 519 C-124s would have been $1,271,550,000. Including RDT&E, the program cost is then $1,403,550,000. To account for government-funded capital supplied to the contractor, this figure is increased by 4.6 percent to a total of $1,468 million. Total pounds of empty weight delivered for 519 planes was 52,500,000; total pounds of useful capacity, 59,806,965. The C-124 cost $27.95 per pound of empty weight and $24.55 per pound of useful capacity. From the analysis for the Constellation (Table J-4), we saw that it cost $31.55 per pound of empty weight and $41.24 per pound of useful capacity. In comparing the military plane to the civilian, the ratio per pound of empty weight is 0.89; and the ratio per pound of useful capacity is 0.60. Thus, the military C-124 cost about 11 percent less per pound of empty weight than the Lockheed Constellation and 40 percent less per pound of useful capacity.

k. C-124 Versus DC-6

Estimated RDT&E for the C-124 is $132 million. From the progress curve (Figure J-2), we note that through unit 537 (total number of DC-6s built) the cumulative average cost is $2,440,000. Thus, if a total of 537 C-124s had been built, they would have cost $1,310 million. The program cost would then be $1,442 million. Since this total must be increased by 4.6 percent, the total program cost would be $1,509 million. Total pounds of empty weight delivered for 537 aircraft would be 54,300,000; total pounds of useful capacity, 61,881,195. The C-124 cost $27.77 per pound of empty weight and $24.39 per pound of useful capacity. In comparison with the DC-6, which cost $28.11 per pound of empty weight and $30.13 per pound of useful capacity (see Table J-5), the military costs per pound of empty weight and per pound of useful capacity versus the commercial costs per pound of empty weight and per pound of useful capacity yield ratios of 0.99 and 0.81, respectively.

l. C-124 Versus DC-7

Projected costs are not needed for comparison here, since more C-124s were produced than DC-7s. The C-124's total cost, including RDT&E, through 336 planes is $988,120,000 (Table J-8). To account for government-funded capital supplied to the contractor, the total cost is increased by 4.6 percent, to total $1,033 million. Delivering 33,900,000 pounds of empty weight and 38,718,960 pounds of useful capacity, the C-124 cost $30.45 per pound of empty weight and $26.68 per pound of useful capacity. The price per pound of empty weight for the DC-7 is $44.58; the price per pound of useful capacity, $57.77 (see Table J-6). The ratios of the cost per pound of empty weight and per pound of useful capacity for the C-124 to the cost per pound of empty weight and per pound of useful capacity for the DC-7 are 0.68 and 0.46, respectively. On a basis of price per pound of empty weight, the C-124 cost 32 percent less than the DC-7; and on a basis of price per pound of useful capacity, 54 percent less.

2. Turboprop Aircraft - Case Study: C-130 Versus Electra

The Electra was the only turboprop commercial airliner completely designed and produced in the United States. It was developed by Lockheed and powered by four Allison turboprop engines. Lockheed also developed for the U.S. Air Force the C-130 transport, powered by the same basic engine.

Table J-9 presents data for the Electra airliner. Note that the total program consisted of 164 aircraft delivered over the four-year period, 1958-61. Sales prices are shown in both current and 1970 dollars. Total empty weight delivered was 9,212,000 pounds; total useful capacity, 9,320,700 pounds. The total receipts from flyaway sales to the airlines were $492,670,000 (in 1970 dollars). In 1961-62, Lockheed reported a total write-off loss of $120,738,000 on the Electra. This loss converted to 1970 dollars is $153,337,360. Thus, the total cost to Lockheed for the Electra program was $646,007,260. Hence, for the Lockheed Electra, the actual price per pound of empty weight was $70.13; and, per pound of useful capacity, $69.31.

Table J-10 presents data for the C-130 similar to that for the Electra. Table J-10 includes only the first 164 C-130As delivered so as to normalize the number of military aircraft to the total number in the Electra program. We have assumed that the total weapon-system cost for the first nine aircraft was made up solely of flyaway and RDT&E costs. Since there were so few aircraft, the spares and ground-support-equipment procure-

Table J-9. ELECTRA PROGRAM DATA

Year	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Price (million current $)	Price (million 1970 $)	Total Price (million 1970 $)
1958	56.0	12	672	684	2.053	2.74	32.88
1959	56.0	107	5,992	6,099	2.265	2.99	319.93
1960	56.0	24	1,345	1,368	2.290	2.94	70.56
1961	57.3*	21	1,203	1,170	2.600	3.30	69.30
Total		164	9,212	9,321			492.67

*Strengthened wing introduced in production in early 1961. Aircraft delivered earlier were modified.

Table J-10. C-130 PROGRAM DATA

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	RDT&E and Procurement Cost (million current $)	RDT&E and Procurement Cost (million 1970 $)
1952	--	--	0	--	--	0.5[a]	0.72
1953	YC-130A C-130A	59.33 59.33	2 7	534	584	159.5[a]	227.45
1954	C-130A	59.33	20	1,187	1,297	94.2[b]	132.54
1955	C-130A	59.33	48	2,848	2,114	117.0[b]	162.40
1956	C-130A	59.33	84	4,984	5,449	168.2[b]	230.43
1957	C-130A	59.33	3[c]	178	195	6.0[b,c]	6.11
Total			164	9,731	10,639		761.65

[a] Total program funds.

[b] Flyaway costs only.

[c] Part of an order for 45 C-130As; unit price assumed same as for 1956.

ment in that first increment was probably small. For the subsequent years, we have used only the flyaway costs, on the assumption that the RDT&E phase should have been nearly completed after the delivery of the first nine aircraft. Using these assumptions, the empty weight for the first 164 aircraft delivered was 9,731,000 pounds (and the useful capacity, 10,639,008 pounds), for a total cost to the Air Force of $761,650,000 (see Table J-10). To account for government-provided capital, the price paid to Lockheed should be increased by 4.6 percent, for a resulting $796,685,900. Hence, the average price per pound of empty weight for the C-130 program for the first 164 aircraft was $81.87; the average price per pound of useful capacity, $74.88.

The ratio of price per pound of empty weight for the C-130 versus the Electra was $81.87/$70.13, or 1.17; the ratio of price per pound of useful capacity, $74.88/$69 31, or 1.08. In other words, the comparison of these two programs indicates that DoD paid 17 percent more per pound of empty weight (and 8 percent more per pound of useful capacity) for the C-130 than the commercial airlines paid for the similar Electra. Access to data at Lockheed confirmed our general results. The C-130 required more production man-hours per pound than the Electra.

3. Jet Aircraft - Case Studies

a. KC-135/C-135 Versus Boeing 707

The KC-135/C-135 was compared to its commercial equivalent, the Boeing 707. Total empty weight delivered on 704 KC-135/C-135s (the total number of 707s delivered through 1972) was 68,648,000 pounds; total useful capacity, 108,496,710 pounds. The total procurement and RDT&E cost of $3,290,360,000 (see Table J-11) increased by 4.6 percent for government-funded capital yields a total of $3,441,716,560, for a cost per pound of empty weight of $50.14 for the KC-135/C-135 program and a cost per pound of useful capacity of $31.72. Total sales of the 707 came to $5,549,680,000 (see Table J-12). Total pounds of empty weight delivered was 89,134,000, for a price of $62.26 per pound of empty weight on the Boeing 707; total pounds of useful capacity was 118,056,373, for a price of $47.01 per pound of useful capacity. The ratio of the price per pound of empty weight for the KC-135/C-135 to the price per pound of empty weight for the Boeing 707 is 0.80; the ratio of the price per pound of useful capacity for the KC-135/C-135 to the price per pound of useful capacity for the Boeing 707 is 0.67. Thus, on a basis of price per pound of empty weight, the KC-135/C-135 cost approximately 19 percent less than the comparable Boeing 707; and, on a basis of price per pound of useful capacity, 33 percent less.

Table J-11. KC-135/C-135 PROGRAM DATA

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Procurement Cost (million current $)[a]	RDT&E and Procurement Cost (million 1970 $)[b]
1955	KC-135A	97	29	2,813	4,437	281.2	390.31
1956	KC-135A	97	68	6,596	10,404	295.8	405.25
1957	KC-135A	97	118	11,446	18,054	398.6	538.91
1958	KC-135A	97	130	12,610	19,890	368.6	492.08
1959	KC-135A	97	81	7,857	12,393	216.5	285.35
1960	KC-135A C-135A	97 105	56 10	6,482[c]	8,568 1,704	171.1[d]	219.86
1961	KC-135A C-135A,B	97 105	65 20	8,405[c]	4,945 3,409	206.2[d]	261.87
1962	KC-135A C-135B	97 105	84 15	9,723[c]	12,852 2,557	273.3[d]	347.09
1963	KC-135A	97	28[e]	2,716	4,284	63.5	80.64[e]
Total			704	68,648	103,497		3,290.36

[a] Flyaway costs only.

[b] An RDT&E estimate of 50 times the cumulative average cost of 100 units, or 50 x 5.38 = 269.00

[c] The total pounds delivered are prorated by quantity and weight of the two models.

[d] Total flyaway costs for both programs.

[e] Part of a lot of 88; unit price in 1963 assumed.

b. C-5A Versus Boeing 747

Developed at about the same time, the Lockheed C-5A and the Boeing 747 are similar in size, technology, and aerodynamic performance characteristics. However, some of the features incorporated in the C-5A tended to increase its cost per pound of empty weight relative to that of the 747. In particular, the C-5A is equipped with a sophisticated inertial navigation sys-

Table J-12. BOEING 707 PROGRAM DATA

Year	Model[a]	Empty Weight (thousand pounds)[b]	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Price (million current $)[c]	Price (million 1970 $)	Total Price (million 1970 $)
1958	707-120 707-120B 707-220 707-320	117	7	819	[illegible]	4.90	6.54	45.78
1959	"	117	73	5,541	10,147	4.40	5.80	423.40
1960	"	117	58	7,956	9,452	5.50	7.07	480.76
1961	"plus 707-320B 707-320C 707-420	124	11	1,364	1,472	5.90	7.49	82.39
1962	"	124	38	4,712	5,086	6.20	7.87	299.06
1963	"	124	28	3,472	3,748	6.75	8.57	239.96
1964	"	130	32	4,160	5,824	6.76	8.48	271.36
1965	"	130	54	7,020	9,828	6.75	8.27	446.58
1966	"	130	77	10,010	14,014	7.00	8.19	630.63
1967	"	130	113	14,690	20,566	7.25	8.21	927.73
1968	"	130	111	14,430	20,202	7.50	8.22	912.42
1969	"	130	59	7,670	10,738	8.00	8.33	491.47
1970	"	130	19	2,470	3,438	8.50	8.50	161.50
1971	"	130	10	1,300	1,820	10.00	9.72	97.20
1972	"	130	4	520	729	10.50	9.86	39.44
Total			704	89,134	116,056			5,549.68

[a] Years 1958-60 include four 707 models; subsequent years include seven models.

[b] Average empty weight for all models.

[c] Average price for all models.

tem, has a soft-field-landing capability, and has both nose and tail loading ramps. The soft-field landing-gear and loading ramps add weight as well as cost to the airplane and, on the dollar-per-pound basis of our analysis, may not be significantly different from the average dollars per pound for the 747 empty weight. However, the avionic equipment certainly tends to increase the price per pound of the C-5A relative to that of the 747.

Table J-13 presents data for the 747. The 747 will probably remain in production for a number of years. Numbers delivered during the first four years of its production life were quite similar to numbers of DC-8 deliveries (see Table 13, above, Ch. V). During the first four years of production, 197 747s were delivered, compared to 176 DC-8s. We will assume that total deliveries and production life-span will be the same as for the DC-8 (556 airplanes and 15 years).

Table J-13. BOEING 747 PROGRAM DATA*

Year	Number Delivered	Price (million current $)	Price (million 1970 $)
1969	4	19.0	19.8
1970	92	21.0	21.0
1971	69	23.5	22.9
1972	30	24.0	22.6
Total	195		

*Average empty weight: 355,000 pounds; average useful capacity: 347,484 pounds.

Table J-14 shows prices in current and constant dollars for the Boeing 707-320. Over the 15-year period, the price of the 707-320 has increased at an average of 2.15 percent per year in real terms. Assuming that the 747 will increase at this same rate, its average price (at the midpoint of its production life) will be \$19,800,000 x $(1.0215)^7$ = \$23 million in 1970 dollars. Total receipts from flyaway sales prices to the airline would be 556 x \$23 million = \$12,800 million; and empty weight delivered would be 556 x 355,000 = 197 million pounds. Hence, the price per pound to the airlines would be \$12,800 million / 197 million = \$64.97.

Table J-15 presents C-5A program cost data. The current-year dollar figures have been converted to 1970 dollars by the cost index of Table J-1. A total of 81 airplanes was built. Unit flyaway costs were converted to a cumulative-average basis

Table J-14. BOEING 707-320 PRICES

Year	Current Dollars (millions)	1970 Dollars (millions)
1958	5.4	7.2
1961	6.0	7.6
1962	6.2	7.9
1963	6.8	8.6
1964	6.8	8.5
1965	6.8	8.3
1966	7.1	8.3
1971	8.5	8.3
1972	10.3	9.7

Table J-15. C-5A PROGRAM COSTS

Year	RDT&E (million 1970 $)	Procurement (million 1970 $)	Quantity	Unit Flyaway Cost (million 1970 $)
1964	550.6	--	--	--
1965		--	--	--
1966		--	5	110.1
1967		728.4	8	[illegible]
1968	--	770.3	18	42.8
1969	--	776.0	27	28.7
1970	--	775.9	23	32.9
Total	550.6	3,030.6	81	

and plotted on Figure J-3, and a trend line was fitted through the points. We have assigned all the RDT&E cost ($550.6 million) to the flyaway cost of the five R&D aircraft. This data point appears consistent with the four other data points of Figure J-3. The resulting progress-curve slope is 80 percent, a typical value

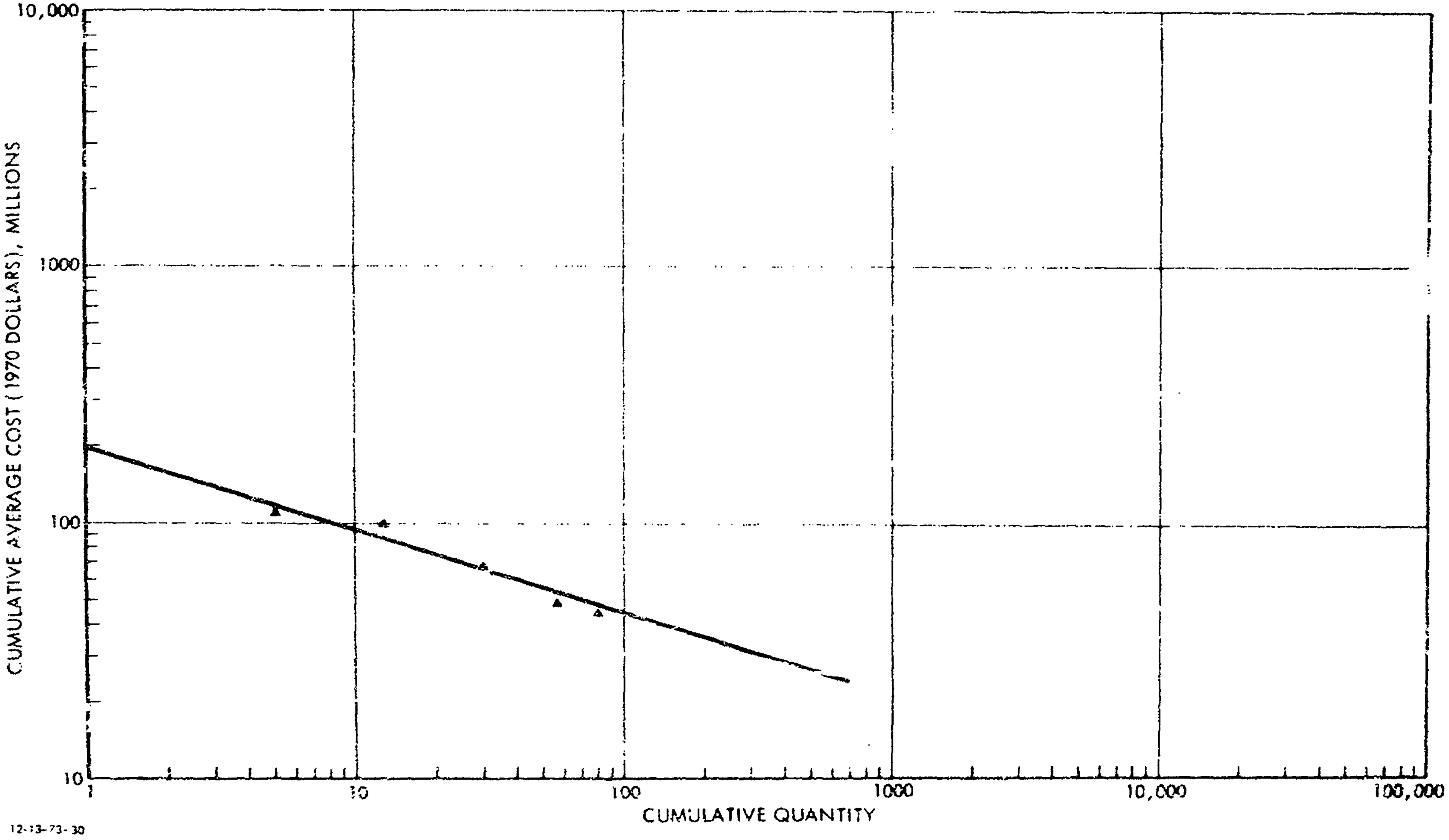


Figure J-3. C-5A COST-QUANTITY RELATIONSHIP for aircraft progress curves. It is possible that there were some other RDT&E costs not included in the $550.6 million figure.

In order to normalize the C-5A program prices for number of aircraft built, it is estimated from Figure J-3 that the C-5A cumulative average cost would have been $25.3 million if production had been continued to a total of 556 aircraft. C-5A total cost for a program of 556 aircraft would have been 556 x $25,300,000 = $14,066,800,000. This figure is probably somewhat low for two reasons: (1) as discussed above, we may be missing some RDT&E costs other than the five R&D aircraft flyaway costs; and (2) Lockheed lost money on the program. No attempt has been made to correct for these two factors. To account for government-provided capital, the price paid to Lockheed should be increased by 4.6 percent: $14,066,800,000 x 1.046 = $14,713,872,800.

The empty weight of the C-5A is 321,000 pounds. Hence, total empty weight for 556 aircraft would have been 556 x 321,000 = 178,476,000 pounds; and the average price per pound of empty weight for a C-5A program of 556 aircraft would have been $14,713,872,800/178,476,000 = $82.44.

The ratio of price per pound of empty weight for the C-5A versus the 747 was $82.44/$64.97 = 1.27. The price per pound of empty weight for the C-5A was about 27 percent greater than for the 747.

Using the same cost data as described above for the C-5A and the Boeing 747, but comparing costs per pound of the two aircraft on a basis of useful capacity (instead of empty weight), our results showed the C-5A to cost about 6 percent less than the Boeing 747. One argument for this change in ratios can be explained by reference to our definition of useful capacity as aircraft maximum gross takeoff weight minus empty weight. As mentioned previously, the empty weights of the two aircraft are close, with the C-5A only 30,000 pounds lighter; but the maximum gross takeoff weight of the C-5A is greater by approximately

60,000 pounds than that of the Boeing 747. Thus, 80,000 pounds per C-5A aircraft will be included in the total pounds to be divided into the same cost used for empty weight. Actual useful-capacity data for the C-5A are 556 x 424,821 pounds = 236,200,476 pounds of useful capacity; the average price per pound of useful capacity for 556 aircraft would have been $14,713,872,800 / 236,200,476 = $62.29. Similarly, for the Boeing 747, we would have 556 x 347,484 pounds = 193,201,104 total pounds of useful capacity; the average price per pound of useful capacity would have been $12,800 million / 193,201,104 = $66.25. Therefore, the ratio of price per pound of useful capacity for the C-5A versus the Boeing 747 was $52.29/$66.25 = 0.94--indicating that the C-5A cost about 6 percent less than the Boeing 747.

c. B-52 Versus Boeing 707

In Table J-12, it was shown that the average costs per pound of empty weight and of useful capacity for 704 Boeing 707s were $62.26 and $47.01, respectively. The comparable data for the B-52 are shown in Table J-16. The production quantity data were taken from *Project BACKFILL* [24]; the cost data were provided by the Cost and Economic Analysis Division, Comptroller of the Air Force (AFACM); and the empty weights for each model of B-52 were taken from the *USAF Standard Aircraft/Missile Characteristics (Green Book)*.

Before normalizing for quantity for the comparison with the 707 program, the total B-52 program cost (per pound of empty weight) works out as follows:

Total flyaway cost		$8,030,600,000
Preproduction R&D	+	245,100,000
		$8,275,700,000
Factor for government capitalization	x	1.046
		$8,656,380,000
Total empty weight	÷	129,469,014 lb
	=	$66.86/lb

Table J-16. B-52 PROGRAM DATA[a]

Year	Model	Empty Weight (thousand pounds)	Number Delivered	Empty Weight Delivered (thousand pounds)	Useful Capacity Delivered (thousand pounds)	Total Flyaway Cost (million 1970 $)
1952	B-52A,B	178[b]	20	3,556	5,444	754.8
1953	B-52B,C	178	43	7,646	11,704	531.6
1954	B-52C	178	25	4,445	6,805	236.7
1955	B-52D	178	77	13,692	20,958	833.4
1956	B-52D B-52E	178 175	93 40	23,528	25,313 11,009	1,064.2
1957	B-52E B-52F B-52G	175 174 171	60 89 53	35,012	16,513 24,500 16,801	2,003.5
1958	B-52G	171	101	17,293	32,017	967.9
1959	B-52G	171	39	6,677	12,363	376.2
1960	B-52H	173	62	10,710	19,546	769.7
1961	B-52H	173	40	6,910	630	492.6
Total			742	129,469	203,703	8,030.6

[a] RDT&E: $245.1 million (1970 dollars).

[b] Assumed to be the same as models C and D.

Similarly, for 742 B-52s, the total pounds of useful capacity are 215,682,481. Dividing the final cost of 742 B-52s by the total pounds of useful capacity, we find that a B-52 costs $8,656,380,000 / 215,682,481 = $40.13 per pound of useful capacity.

To normalize for quantity for comparing with the 704-aircraft 707 program, the cost and weight of the last 38 B-52H aircraft are subtracted from the program, resulting in the following:

Total flyaway cost	$7,562,630,000
Preproduction R&D	+ 245,100,000
	$7,807,730,000
Factor for government capitalization	x 1.046
	$8,166,890,000
Total empty weight	÷ 122,904,894 lb
	= $66.45/lb

Similarly, for 704 B-52s, the total pounds of useful capacity are 203,702,601. Dividing the final cost of 704 B-52s by the total pounds of useful capacity, we find that a B-52 costs $8,166,890,000 / 203,702,601 = $40.09 per pound of useful capacity.

The reason that the cost per pound at 704 units is less than that at 742 units is that the increase in B-52 unit price due to model changes is much greater with the later models than is the decrease in unit price due to the learning effect. This "tailing up" is clearly seen in Figure J-4, which plots each year's B-52 production at the lot midpoint for the year against the unit price for that year.

If (instead of subtracting the end production from the B-52 program) a progress curve is calculated from the AFACM data and the total flyaway cost of 704 B-52s is taken from it, the results are as follows:

Total flyaway cost	$7,401,710,000
Preproduction R&D	+ 245,100,000
	$7,646,810,000
Factor for government capitalization	x 1.046
	$7,998,560,000
Total empty weight	÷ 122,904,894 lb
	= $65.08/lb

Similarly, for 704 B-52s, dividing the final cost derived from a progress curve by the total pounds of useful capacity, we find

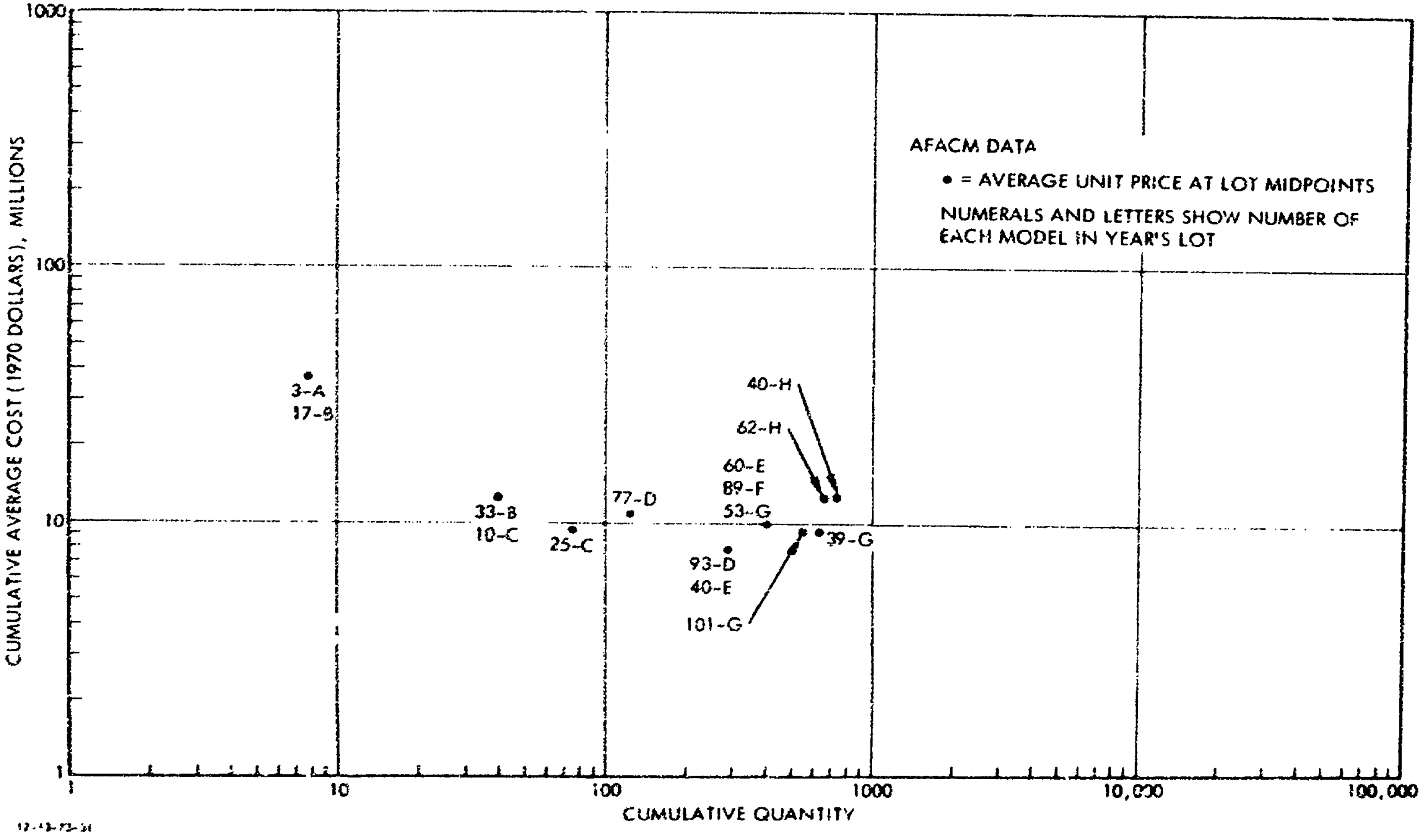


Figure J-4. B-52 UNIT FLYAWAY COSTS VERSUS QUANTITY that a B-52 costs $7,998,560,000 / 203,702,601 = $39.27 per pound of useful capacity.

The results, whichever way is used, are surprisingly close to the $62.26 per pound of empty weight (and the $47.01 per pound of useful capacity) for the 707.

4. Data for Aggregated Comparison

Table J-17 presents in tabular form the data used to make the aggregated comparison of military and commercial aircraft presented in Figures 19 and 20 of the main report.

B. COMPARISON OF MILITARY AND COMMERCIAL SHIPS

Navy combatant ships have many features and much equipment not found in commercial ships, and any valid comparison of construction costs of Navy and commercial ships would be most difficult. Further, since regular Navy auxiliary ships are designed to operate with fighting fleets, they nearly always have extra features (such as equipment for underway replenishment of ships at sea) that make their construction costs higher than those of comparable commercial ships.

The Military Sealift Command (MSC) is responsible for shipment by sea of supplies, material, and personnel of the three services. MSC has embarked on a "Build and Charter" program, under which contracts are let to commercial firms to build ships to MSC specification for charter on a long-term basis. MSC contracted in June 1972 for nine 25,000-deadweight-ton (DWT) tankers under the "build and charter" arrangement. The only "build and charter" ship now in service is the *Admiral Callaghan*, a roll-on/roll-off (RO/RO) ship built in 1967.

Case studies for both the tankers and the RO/RO ships are presented below. They were compared on a basis of unit price versus weight.

Table J-17. DATA USED FOR AGGREGATED COMPARISON OF MILITARY AND COMMERCIAL AIRCRAFT PRICES

Aircraft	Type[a]	Cumulative Average Cost (million 1970 $)	Cumulative Average Empty Weight (thousand pounds)	Cumulative Average Useful Capacity (thousand pounds)	Quantity of Aircraft Produced
Military					
C-119	P	0.99	40	29	1,036
C-123	P	1.08	31	27	472
C-124	P	2.97	101	115	446
C-130	T	4.46	59	65	600
C/KC-135	J	3.61	98	154	777
C-141	J	8.59	134	189	284
C-5A	J	44.96	321	425	81
B-52	J	11.67	175	291	742
C-121	P	2.97	73	72	117
KC-97	P	1.84	88	88	810
C-133	T	12.47	117	172	50
Commercial					
Convair 240,340,440	P	0.81	29	16	563
Constellation	P	2.11	67	51	519
DC-6	P	1.47	52	49	537
DC-7	P	3.07	69	53	336
Lockheed Electra	T	3.94[b]	56	57	164
Boeing 707	J	7.88	127	168	704
DC-8	J	8.30	135	174	556
Boeing 747	J	21.89	355	347	[illegible]95
Boeing 727	J	5.64	80	78	868
Boeing 737	J	3.78	58	49	311
Martin 202-204	P	0.58	27	11	103
DC-9	J	4.00	49	43	649
Lockheed L1011	J	18.00	250	196	17
Jetstar	J	1.79	22	20	150[c]
Gulfstream I	T	1.32	22	15	200
Gulfstream II	J	2.90	37	29	42[d]
Learjet	J	0.72	7	7	325
Convair 880-990	J	9.70[e]	100	115	124
Fairchild F-27	T	0.95	25	19	126

[a] P = piston; T = turboprop; J = pure jet.

[b] Includes reported losses of Lockheed.

[c] Approximate.

[d] As of February 1969.

[e] Includes reported losses of General Dynamics.

1. Case Study: MSC 25,000-DWT Tankers Versus Commercial Tankers

Nine 25,000-DWT tankers, all of which will be owned by Marine Ship Leasing Corporation, are being built under the "build and charter" program. Five of the ships are being built by Bath Iron Works Corporation, and four by Todd Shipyards Corporation. Price per ship for each group is $16 million.

All tankers between 25,000 and 120,000 DWT under construction and on order in U.S. yards as of 1 February 1973 are shown in Table J-18.

Table J-18. U.S.-BUILT TANKER PRICES*

Builder	Number of Tankers	Deadweight Tons	Unadjusted Unit Price (million current $)	Mean Delivery Date	Unit Price (million 1974 $)
For MSC					
Bath	5	25,000	16.0	8/74	16.0
Todd	4	25,000	16.0	8/74	16.0
For Commercial Operators					
Bethlehem Steel	3	120,000	30.0	2/74	31.8
Bethlehem Steel	1	69,800	18.0	6/73	19.[illegible]
Bethlehem Steel	1	120,000	30.0	11/73	31.[illegible]
Gunderson	3	35,000	16.1	12/74	15.9
National Steel	3	38,300	18.2	8/74	18.2
National Steel	3	90,000	27.9	3/75	27.2
Sun Shipbuilding	1	80,000	18.0	3/73	19.1
Todd	4	35,000	19.4	11/75	18.6

*All tankers between 25,000 and 120,000 DWT under construction and on order, 1 February 1973.

Sources: *February 1, 1973, Merchant Shipbuilding Report*, Shipbuilders Council of America, Washington, D.C.; and *Merchant Marine Data Sheets*, Maritime Administration, U.S. Department of Commerce.

Since 1969, shipbuilding costs have been increasing at about 5 percent per year (see Table J-19). The average delivery date of the nine tankers for MSC (August 1974) was taken as the base date, and prices for delivery dates of commercial tankers before or after that time were adjusted in the last column of Table J-18 to reflect the 5-percent-per-year increase in shipbuilding costs. These adjusted prices versus DWT are plotted in Figure 21 (see Ch. V, above). The price of $16 million for the MSC tankers appears within the normal commercial price trend for tankers from 25,000 to 120,000 DWT.

Table J-19. INDEX OF ESTIMATED SHIPBUILDING COSTS IN THE UNITED STATES

Year	Index	Percent Increase	Year	Index	Percent Increase
1958	285	--	1966	318	1.6
1959	292	2.5	1967	331	4.1
1960	295	1.0	1968	343	2.4
1961	297	0.7	1969	359	4.7
1962	299	0.7	1970	379	5.6
1963	303	1.3	1971	399	5.3
1964	311	2.6	1972	418	4.8
1965	313	0.6			

Source: *Index of Estimated Shipbuilding Costs in the United States*, Maritime Administration, U.S. Department of Commerce, 31 May 1972.

2. Case Study: Roll-On/Roll-Off Ships (MSC Versus Commercial)

Table J-20 lists the RO/RO ships delivered by U.S. shipyards through 1972. The first two are owned by MSC, and the third is under long-term charter to MSC. The remainder are in commercial service. The total acquisition costs for the *Comet* and *Meteor* were somewhat higher than those shown in Table J-20 (see note,

Table J-20. U.S.-BUILT ROLL-ON/ROLL-OFF SHIP PRICES

Builder	Ship	Gross Tons	Contract Price (million current $)	Delivery Date	Price, Adjusted to 1967 Delivery (million 1967 $)
MSC or MSC-Chartered					
Sun Shipbuilding	*Comet*	13,792	11.00*	1/58	12.8
Lockheed	*Sealift*	12,000	15.90*	4/67	15.9
Sun Shipbuilding	*Adm. Callaghan*	20,900	20.00	12/67	20.0
Commercial					
Sun Shipbuilding	*Ponce de Leon*	20,900	20.00	3/68	19.3
Ingalls	*Mormacsea*	14,400	15.95	4/69	14.7
Ingalls	*Mormacsky*	14,400	15.95	7/69	14.7
Ingalls	*Mormacstar*	14,400	15.95	9/69	14.7
Ingalls	*Mormacsun*	14,400	15.90	2/70	14.7
Sun Shipbuilding	*Eric K. Holzer*	20,900	19.00	12/70	16.6
Sun Shipbuilding	*Fortaleza*	15,130	23.20	12/72	18.4

*Acquisition costs obtained from MSC were $11.552 million (*Comet*) and $17.009 million (*Sealift*). The difference is due to equipment not included in builder's contract price.

Source: Shipbuilders Council of America.

Table J-20). We have used the builder's contract price for all ships, since they were all obtained from the Shipbuilders Council of America and should be the most comparable prices. Contract prices have been adjusted in the last column of Table J-20 to a 1967 delivery date by use of the cost index of Table J-19. These 1967 prices are plotted versus gross tons in Figure 22 (see Ch. 7, above). The price of the *Admiral Callaghan* was probably increased somewhat by the installation of a gas-turbine powerplant. The *Admiral Callaghan* was intended to investigate the feasibility of large gas-turbine-powered ships. All the other ships are equipped with conventional steam powerplants.

As Figure 22 indicates, prices of the MSC RO/RO ships lie within the normal range of commercial RO/RO ship prices.

C. WHEELED VEHICLES

Section D of Chapter V presented statistical results for the comparison of military and commercial wheeled vehicles. The data points of Figure 23 and the analysis were based on the data in Table J-21. Vehicles are listed by name, number of axles, price in 1970 dollars, and curb weight--for both military and commercial vehicles.

Table J-21. WHEELED-VEHICLE DATA

Vehicle Designation	Number of Axles	Price (1973 $)	Weight (pounds)
Commercial Vehicles			
Ford U900	3	21,295	13,170
Ford U915	3	25,525	13,515
Ford F805	2	8,190	6,225
Ford F808	2	9,410	6,625
Ford X905	3	24,490	13,575
Ford X908	3	24,475	13,615
Ford C907	2	11,650	7,875
Ford C915	2	12,905	7,965
Ford Z904	2	21,350	10,735
Ford Z903	2	22,335	10,980
GMC MH9670	3	21,999	13,405
GMC MH9700	3	22,074	13,590
GMC HH7671	2	9,203	7,290
GMC CE6670	2	5,259	6.835
GMC DI9692	3	22,191	13,160
GMC DI9702	3	22,216	13,195
GMC TV7731	2	11,990	8,400
GMC FN9672	2	19,614	10,935
IHC F4270	3	27,322	13.693
IHC L0850	2	9,141	7,427
IHC COF407	3	27,689	13,605
IHC CO1910	2	10,908	8,242
IHC CO4070	2	24,209	10.530
Commercial HET	4	50,000	33,500
IHC 8500	3	50,000	30,000
Kenworth 852	3	95.000	46.000
MACK F871EX	3	55,000	37.000
IHC Pick-up, 10/10 C&C	2	2.942	3,135

(continued on next page)

Table J-21. (continued)

Vehicle Designation	Number of Axles	Price (1973 $)	Weight (pounds)
IHC Pick-up, 11/10 C&C	2	3,052	3,209
IHC Pick-up, 10/10 8 foot	2	3,130	3,302
IHC Pick-up, 11/10 8 foot	2	3,216	3,619
IHC Pick-up, 13/10 C&C	2	3,834	3,513
IHC Pick-up, 13/10 8 foot	2	3,999	3,923
IHC Travelall 100, 4x2	2	4,125	4,271
IHC Travelall 200, 4x2	2	4,381	4,504
IHC Travelall 100, 4x4	2	5,014	4,467
IHC Travelall 200, 4x4	2	5,168	4,741
IHC Scout, Wagon, 4x2	2	2,979	3,370
IHC Scout, Wagon, 4x4	2	3,676	3,600
IHC Scout, Cab Top, 4x2	2	2,832	3,290
IHC Scout, Cab Top, 4x4	2	3,521	3,500
Military Vehicles			
Truck, Ambulance, X38365	2	4,632	3,700
Truck, Cargo, X39598	2	2,240	3,590
Truck, Carryall, X42064	2	3,178	3,235
Truck, Delivery, X54531	2	3,679	5,400
Truck, Panel, X54805	2	3,050	2,950
Truck, Stake, X56038	2	2,540	4,460
Truck, Stake, X56449	2	4,325	6,894
Truck, M26	3	74,016	27,700
Truck, M123	3	42,713	29,659
Truck, M819	3	19,385	34,490
HET, XM 746	4	86,000	48,700
HET, Austere	4	81,000	46,000
M561, 1-1/4 ton	3	13,364	7,480
M656, 5 ton	4	20,000	15,150
M656, 5 ton, w/wench	4	20,500	16,720

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Table J-21. (concluded)

Vehicle Designation	Number of Axles	Price (1973 $)	Weight (pounds)
M454, Fire Truck	3	26,420	16,140
Truck, 3/4 ton	2	5,207	5,955
Truck, 2-1/2 ton	3	13,035	15,900
Truck, 5 ton	3	19,385	24,000
Truck, 1/4 ton	2	3,701	2,487
Truck, 8 ton	2	58,596	33,835
Truck, LF, 6,000 pounds	2	32,526	20,000
Truck, LF, 10,000 pounds	2	44,204	30,760