IMPACTS OF PRODUCTION RATE ON WEAPON SYSTEM COSTS

BY
James D. Dorsett
Cost Analyst
Directorate of Cost Analysis
Deputy Chief of Staff/ Comptroller
Headquarters Air Force Systems Command
Andrews AFB, Maryland

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1.0 INTRODUCTION

The Department of Defense has limited alternatives when defense budgets are reduced. Procurement programs can be decreased and/or eliminated, R&D can be reduced, and/or operations and manpower can be cut back. To meet this Administration's Zero Growth Budget the military services initially opted for near term production rate decreases and program stretchouts. The Air Force Chief of Staff stated that procurement levels of major programs like the C-17, F-16, F-15, B-2 and ATF will be reduced to meet the zero growth budget. The Navy looked at possible stretchouts of the F-18, F-14, V-22 and other aircraft programs. Secretary Cheney has recommended that the F-14D (new production), V-22, F-15E and AH-64 be cancelled or terminated earlier than planned.

Table 1 shows the status of several major programs and the adjustments made to meet recent budget constraints. Note that any termination initiated by DOD can always come back from Congress as a stretched-out program.

	STATUS	CURRENT RATE	PEAK RATE ACHIEVED
AIR FORCE			
F-16C/D	US BUY FY-39=180 DROPS TO 150 FROM FY-90-95 THEN 120 FY 96-97	256 (FY 90)	324 (SHORT TERM PEAK)
B-2	CONGRESSIONALLY MANDATED STRETCHOUTS POSSIBLE	NA	NA
ATF	STRETCHOUT POSSIBLE	NA	NA
F-15E	TERMINATED AFTER FY-91	36	135
C-17	STRETCHOUTS POSSIBLE, STRETCHOUT DRILLS PERFORMED LAST BUDGET CYCLE BUT NO CHANGE IN PROFILE RESULTED	4	29 (PROJECTED)
TACIT RAINBOW	AIR FORCE QUANTITIES REDUCED AFTER NAVY FUNDING ZEROED OUT (STRETCHOUT)	NA	NA
NAVY			
F-18	U.S. BUY (FY 90-94) REDUCED FROM 72/YR TO 66/YR	92	146
F-14D	DOD DIRECTED TERMINATION OF THE F-14D (NEW PRODUCTION) PROGRAM AFTER FY-89. POSSIBLE SLIPPAGE OF F-14D (REMANUFACTURE) PROGRAM TO FY-91.	12	86
LRAACA	NO CHANGE SINCE 1/89	NA	18 (PROJECTED)
V-22	ORIGINAL PROFILE STRETCHED IN PAST DRILLS. PROGRAM THEN TERMINATED BY DOD.	NA	NA
SH-60	18 SH-60F ELIMINATED FROM FY-90 (ONE YR)	24	27
AV-8B	PROGRAM TERMINATED WITH MULTIYEAR BUY OUT. LAST U.S. PRODUCTION YEAR FY-90.	24	70
TACIT RAINBOW	NAVY FUNDING ZEROED OUT AFTER FY-89.	NA	NA

TABLE 1. THE CURRENT STATUS OF MAJOR PROGRAMS

TABLE 1 CONT'D

ARMY

LHX	UTILITY VERSION ELIMINATED CAUSING TOTAL QUANTITY REDUCTION	NA	NA
AH-64	FY 90 & 91 REDUCED FROM 72 TO 66/YR PROGRAM TERMINATED AFTER 91 (-156 A/C)	72	138
CH-47	NO RECENT REDUCTIONS. PROGRAM TERMINATED AFTER FY-92	48	48
UH-60	FY 90 & 91 REDUCED FROM 83 TO 72/YR RATE DROPS TO 60 FY-92-94	72	120
OH-58D	PROGRAM WAS 36/YR THRU FY-94 NOW TERMINATED AFTER FY-89	36	44

1.1 DEFINITION OF FIXED AND VARIABLE COSTS

For the purposes of this report the terms "fixed costs" and "variable costs" will be defined as follows:

Fixed costs - Costs which do not vary directly with quantity procured/produced. These may be totally fixed or semifixed.

Variable costs - Costs which vary directly with quantity.

Some would argue whether certain costs are fixed. Often costs which are considered variable in the long run will initially appear to be fixed due to a companies adjustment period. There is often little incentive for a contractor to reduce capacity and limit future business potential. I wrote this paper from a program office estimator's point of view. Pure micro economic theory and what "should be" were not as important to me as what I thought the contractor could convince the government contracting officer to agree to.

1.2 PURPOSE

The cost estimator working for a program office is faced with the dilemma of estimating the impacts of many different quantity profiles, usually stretchouts, with minimal time and limited resources. Many times the estimators of major programs, with yearly multi-billion dollar budgets, are allowed only a few hours to estimate radically different quantity profiles. For this reason, it is essential that the estimators have production rate sensitivity built into their detailed cost estimating methodologies/models. This paper discusses the application of existing and new production rate estimating methodologies. Methodologies available, their proper application, and my assessment of their strengths and weaknesses will be presented. This paper is not intended to exhaust this subject but, if anything, be a catalyst for discussion. Hopefully, this paper and the OSD symposium briefings will provide a forum for open discussion and exchange of ideas, a sharing of methodologies, and a stimulus for further effort, with possible cross service/agency cooperative research.

1.3 WHY ACCOUNT FOR RATE AT THE DETAILED LEVEL

The rate effect phenomenon impacts not only the prime manufacturer but all of the program's subcontractors and vendors. In order for a cost estimate to be flexible and accurate it must address the rate effect at all levels of procurement. On large complex weapon system procurements, such as aircraft, missiles and major avionics subsystems, the rate effect impacts the different and sometimes numerous companies involved to various degrees. It is therefore my opinion that estimates are more defendable when the rate effect is accounted for at the detailed estimating level. Macro level adjustments for the rate effect seem to involve more subjectivity than discrete and consistent methodologies built in at lower estimating levels.

1.4 CAUSES OF PRODUCTION RATE COST IMPACTS

The two main causes of a cost increase, in a given procurement year, when production rate decreases are the amortization of fixed costs over fewer units (rate effect) and a reduction of learning (learning effect). Learning will not affect the total constant dollar program cost if the inventory objective remains constant, but a quantity reduction in a procurement year will result in higher unit costs for that buy. Of course, the overall then year cost of a stretched-out program will increase due to escalation, as more units are being procured in outyears thus experiencing higher escalation. Tables 2 and 3 show examples of fixed, semifixed and other costs that contribute to the rate effect for aircraft and missile/avionics programs.

PRIME CONTRACTOR

. PORTIONS OF OVERHEAD (1)

.. DEPRECIATION AND AMORTIZATION

... UTILITIES
... REPAIR AND MAINTENANCE
... RENTAL AND SALE OF FACILITIES
... INSURANCE
... PROPERTY TAXES, LICENSES, AND PATENTS
... PLANT REARRANGEMENT
... PLANT SECURITY

.. OTHER

... INDEPENDENT RESEARCH AND DEVELOPMENT (IR&D)
... BID AND PROPOSAL (B&P)
... EMPLOYMENT/RECRUITING
... MARKETING
... EMPLOYEE RELATIONS
... MISCELLANEOUS

.. ALLOCABLE

... CORPORATE ALLOCATIONS
... TRANSFERS FROM DIVISIONS

.. MATERIALS

TABLE 2 - CONTRIBUTORS TO RATE EFFECT FOR AIRCRAFT PROGRAMS

(1) RICHARD A. KATZ, STEPHANIE O. HUBACH, T. BERNARD FOX (MANAGEMENT CONSULTING AND RESEARCH, INC.) ANALYSIS OF DIRECT VERSUS INDIRECT COST

TABLE 2 CONT'D

- PORTIONS OF DIRECT LABOR
  - .. PORTIONS OF SUSTAINING ENGINEERING STAFFS
  - .. VENDOR SUPPORT
  - .. SETUP IN PRODUCTION FABRICATION
  - .. PORTIONS OF FACTORY LABOR ELEMENTS
    - ... PLANNING
    - ... QUALITY ASSURANCE
    - ... TOOLING
    - ... ENGINEERING SUPPORT OF MANUFACTURING
- OTHER POSSIBILITIES
  - .. HIGHER DIRECT LABOR RATES DUE TO LAYOFFS RESULTING IN A MORE SENIOR SKILL MIX.
  - .. INCREASED NEAR TERM PLANNING, QA, TOOLING AND MANUFACTURING SUPPORT TO ALTER PLANT LAYOUT AND MANUFACTURING PROCESS FOR REDUCED QUANTITIES.
  - .. HIRING DISRUPTIONS
  - .. INEFFICIENT USE OF TOOLING AND CAPITAL EQUIPMENT
  - .. SPECIALIZATION OF LABOR NOT MAXIMIZED
  - .. COMPETITION/SECOND SOURCING INITIATIVES NEGATIVELY IMPACTED.
  - .. FEWER FOREIGN MILITARY SALES (FMS) DUE TO HIGHER UNIT COSTS
  - .. FEWER FMS SALES RESULT IN HIGHER UNIT COST FOR U.S.
  - .. FEWER PRODUCABILITY IMPROVEMENTS INITIATED BY THE CONTRACTOR. REDUCED QUANTITIES GIVE THE CONTRACTOR LITTLE INCENTIVE.
- MATERIAL ECONOMIC ORDERING QUANTITIES
- VENDORS AND SUBCONTRACTORS
  - .. ALL THOSE LISTED UNDER PRIME CONTRACTOR TO VARYING DEGREES

PRIME CONTRACTOR

- PORTIONS OF OVERHEAD - SIMILAR TO THOSE PRESENTED IN TABLE 2
- PORTIONS OF DIRECT LABOR
  - .. SETUP AND TEAR DOWN IN TESTING
  - .. SETUP IN PRODUCTION FABRICATION
  - .. SYSTEM ENGINEERING/PROGRAM MANAGEMENT (SE/PM)
  - .. DATA
  - .. SUPPORT LABOR
- PART-TIME LABOR PENALTY - CHANGING ASSEMBLERS FROM ONE BOARD TO ANOTHER.
- MATERIAL ECONOMIC ORDERING QUANTITIES
- OTHER POSSIBILITIES - SIMILAR TO THOSE PRESENTED IN TABLE 2
- VENDORS AND SUBCONTRACTORS
  - .. ALL THOSE LISTED UNDER PRIME CONTRACTOR TO VARYING DEGREES

TABLE 3 - CONTRIBUTORS TO RATE EFFECT FOR MISSILE AND AVIONICS PROGRAMS

2.0 METHODOLOGIES

This section covers various methodologies that may be used to estimate the rate effect caused by the contributors in Tables 2 and 3. These methodologies include discrete costing of fixed and variable costs, overhead modeling, learning curves with rate adjustment, and curve rotation.

2.1 DISCRETE COSTING OF FIXED AND VARIABLE COSTS

One way to produce a rate sensitive cost estimate is to break out the elements which are fixed costs and estimate them independently so their costs are not a function of cumulative quantity. This can be done for fixed costs in overhead and direct labor. Estimating overhead costs will be discussed in the next section. The following are examples of estimating methodologies for direct labor fixed costs.

2.1.1 SETUP

Setups for production fabrication can be broken out of manufacturing fabrication and costed separately if data is available. The equation $Y=AX^B$ can be used in the following manner:

$$Y = AX^B$$

where:

Y = lot average labor hours per setup

A = theoretical first setup hours

X = lot midpoint of setups

B = Log of Slope/Log of 2

This method calculates the setup hours per lot, which will not vary with the quantity run in the fabrication process. Rate sensitivity is realized when setup hours per lot are amortized over varying lot quantities. It should be noted that the total lot hours for this element are usually shared/prorated over each services (Air Force, Army, Navy, etc.) and/or country's (U.S., FMS) quantities procured in that lot.

The analyst should find out when the contractor will change the number of setups per lot as quantity per lot varies. This information can be obtained through discussions with the contractor and/or research of analogous systems produced in the contractors plant, during ramp-up and/or ramp-down.

2.1.2 SUSTAINING ENGINEERING STAFFS

Sustaining engineering that includes Design Configuration Maintenance (ECPs, suppliers support, etc), Support of Delivered Aircraft (engineering analysis of flight/maintenance problems), Program Management and Product Support (Maintainability, etc), does not vary directly with quantity procured and therefore meet my "definition" of fixed costs. This cost element, as defined here, does not include engineers that directly support manufacturing (receiving inspection, fab/assembly support, etc).

Sustaining engineering manhours can be estimated as a function of time and/or a function of rate. Examples of these methodologies are presented below.

- Sustaining Engineering as a function of time.

  $Y = AX^B$

where:

  Y = lot average sustaining engineering hours per unit of time.

  A = theoretical first delivery month sustaining engineering hours

  X = lot midpoint of delivery months

- Sustaining Engineering as a function of Rate and First Lot Dummy Variable.

  $Y = AQ^R(D)$

where:

  Y = lot average sustaining engineering hours

  A = constant

  Q = production rate for given lot

  D = dummy variable for first lot

- Sustaining Engineering as a function of Rate and Time

  $Y = AX^B Q^R$

where:

  Y = lot average sustaining engineering hours per unit of time

  A = theoretical first unit of time sustaining engineering hours

  X = lot midpoint of unit of time

  Q = production rate for given lot

These and other methodologies which do not estimate sustaining engineering as a function of cumulative lot quantity result in rate sensitivity at the unit cost level. Similar to total lot setup hours, total lot sustaining engineering hours should be prorated by service and/or country.

2.1.3 SYSTEM ENGINEERING/PROJECT MANAGEMENT (SE/PM)

SE/PM can be estimated similar to sustaining engineering or man loaded over lot/time. The total lot SE/PM estimate should also be prorated over service and/or country.

2.1.4 QUALITY ASSURANCE, TOOLING, PLANNING, MANUFACTURING ENGINEERING

All of these direct labor elements may include within them a portion of manpower that resembles a fixed staff. Quality Assurance for example, may include a group of engineers who develop and document the inspection standards and whose efforts are required no matter what the production rate. Tooling may require a core staff to maintain tools at set time intervals (beginning of a lot or block, etc) no matter how many pieces are sent through the tooling. All of these elements may require a minimum staff. When quantity is greatly decreased, an estimating methodology totally driven by quantity may produce estimates below these minimum levels. These and other rate effect issues, concerning these cost elements, must be analyzed for each weapon system, manufacturing process and company. The fixed portions of these cost elements should be costed discretely, but it is my experience, that contractors can not or will not provide the discrete data breakouts. An alternative estimating approach is learning curves with rate adjustment ($Y=AX^{B}Q^{R}$), which is covered in a later section.

2.2 OVERHEAD

One of the largest contributors to the rate effect is overhead costs at both the prime and sub/vendor level. This cost element is also one of the most difficult to estimate because of limited data availability and the difficulty of projecting future business base. It appears to me that this element is often ignored or "guesstimated" because of these difficulties.

Projecting a company's long range business base is a difficult task. The analyst will be faced with projecting the company's future business with his or her service, other military services, and the commercial sector. The availability of commercial business and special access required business data will be a problem. The large number of variables to account for and the long period of time to forecast over make some amount of error inevitable, but the alternative is to do nothing but use current Forward Pricing Rate Agreement (FPRA) rates. I believe that attempting to model the company's overhead will be more accurate than the alternative of ignoring the problem.

I would also like to stress that the subcontractor's and vendor's overhead costs must be addressed if the estimate is to be accurate and fully rate sensitive. Increasingly, weapon system prime contractors are becoming integrators of material, subcontractor subassemblies, and other contractor furnished equipment (CFE) versus building all the major portions of the weapon system. Therefore a larger portion of total weapon system cost is incurred at the subcontractors and vendors. Figure 1 shows the distribution of total cost of a modern fighter aircraft procured under a prime and major subcontractor teaming arrangement. Note the large amounts of CFE and subcontract costs. Also note that major subcontractor costs under a teaming arrangement, as many modern, weapon systems are procured, constitute a large percentage of the systems total cost. Overhead models for both the prime and major subcontractor are essential. The rate effect of overhead at the minor subcontractor, intercompany work order (ICWO) and vendor levels must also be estimated.

If time and resources permit, the estimator should model the overhead of the large dollar vendors and subcontracts. Examples include the radar or major airframe contract (empennage, etc) for an aircraft program or major material Weapon Replaceable Assembly (WRA)/Line Replaceable Unit (LRU) of a missile or avionics system.

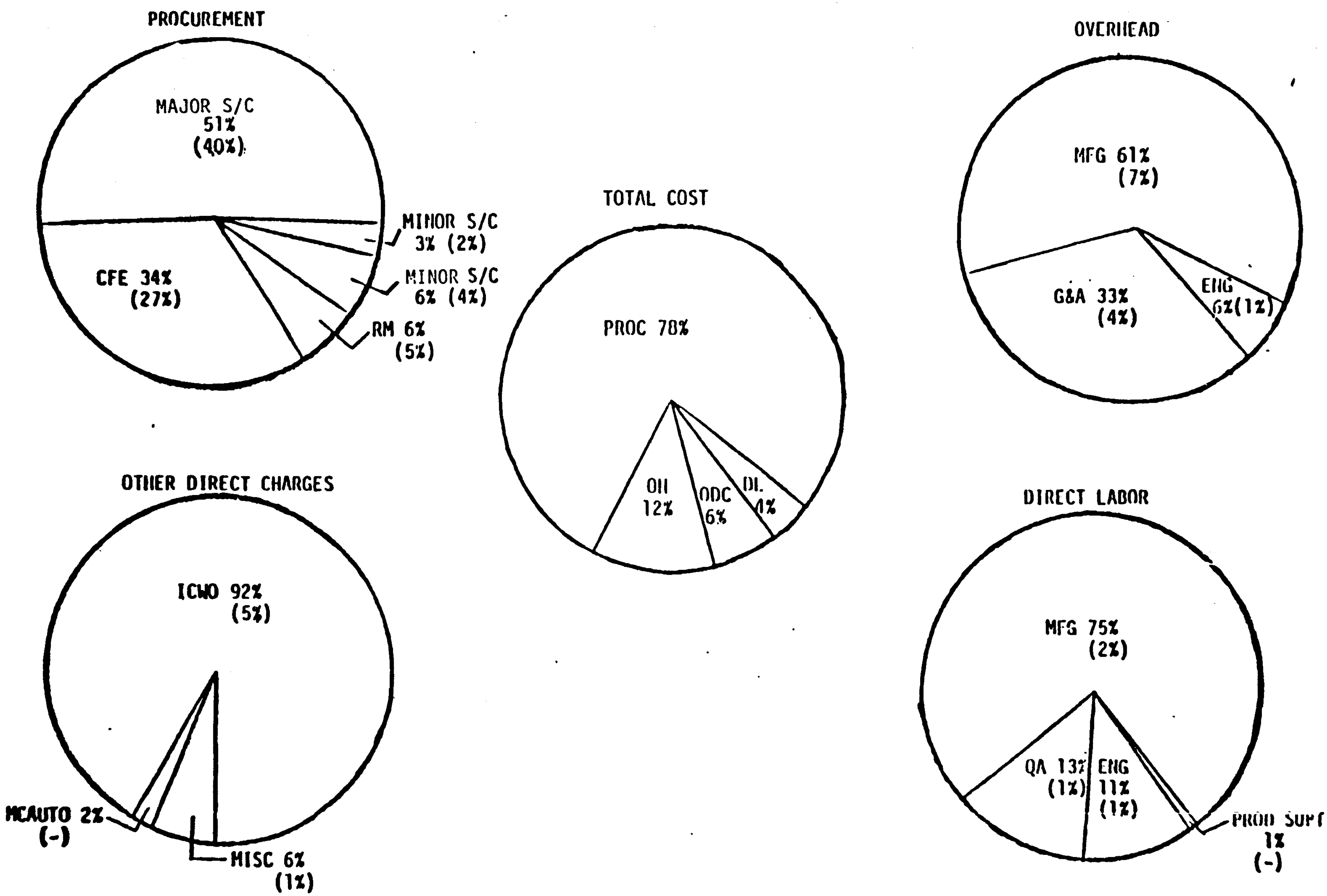


Figure 1 - Distribution of Cost of a Modern Fighter Procurement with a Teaming Arrangement

If time and resources do not permit an overhead analysis, the overhead variance contributing to the overall rate effect can be captured at the macro level, with some inherent error, by using learning curves with rate adjustment. I realize that this does not take into account plant-wide business base, but a qualitative assessment (does this CFE comprise 50% of vendors base? etc) can be factored into the selection of the most appropriate rate adjustment. This methodology's application, strengths and weaknesses will be discussed in a later section.

2.2.1 OVERHEAD MODELS

The availability of overhead models seems to be limited. This section discusses a detailed overhead model developed in the late 1970s by Naval Air Systems Command (NAVAIR) Cost Analysis Division (524), a NAVAIR 524 macro model developed in the early 1980s, and the Institute for Defense Analyses Overhead Model developed in 1986. It has been my experience that the Air Force Plant Representative Office (AFPRO) or Navy Plant Representative Office (NAVPRO) at specific defense contractor plants already have an overhead model for that company. In the past I have attempted to acquire AFPRO or NAVPRO overhead projections for various business base changes (stretchouts, other program terminations etc) with very little success. The AFPRO/NAVPRO has been unable to quickly provide outyear projections. This may have been due to the AFPRO/NAVPRO's limited resources and/or models that are only designed to project budget year and 2 to 3 outyears. Whatever the reason, the need exists for an estimator to have an in-house overhead model that can be used with the input data available and in a timely manner.

2.2.1.1 NAVAIR DETAILED MODEL

The NAVAIR model developed by Mr Phil Pels of the Advanced Concepts Branch (AIR 5242) for McDonnell Douglas Aircraft Co. (MCAIR), St. Louis can serve as an example of one type of overhead modeling to those attempting to develop their own overhead model for a specific company. The model was actually four separate models for engineering, factory, general and administrative (G&A) and material overheads.

The NAVAIR models were based on eight to ten years of contractor data obtained from the company's overhead bid plan. MCAIR bid plans are well organized and contain an extensive amount of data. Each defense contractor must develop projections of their rates and therefore should have adequate data available.

The first step in developing a model would be the normalization of all constant year dollar values to a specific base year. NAVAIR calculates their own escalation indices for each data element using the most appropriate Bureau of Labor Statistics (BLS) Standard Industrial Commodity (SIC) codes or other company/area specific indices. NAVAIR selects the most appropriate code for each element of direct and indirect cost or calculates the weighted average of two or more SIC Codes based on the estimated split of the cost elements, i.e., taxes, pensions, utilities, labor, material, aircraft or electronics, etc. NAVAIR analysts stress the need for this because the escalation between the elements of direct and indirect cost can be substantially different. The derived indices are used for data normalization only. Since they are not used for cost projection, the Office of the Secretary of Defense (OSD) policy on escalation is not broken.

The engineering and factory overhead models were developed using the normalized data by the approach outlined below:

. ID = f (D)

<u>where</u>:

ID = Indirect Headcount (each years' data was one data point)
ID = Direct Headcount (each year's data was one data point)

ID$ = Indirect Labor $ = ID * ID Salary/Person/Year
D$ = Direct Labor $ = D * D Salary/Person/Year

. FB$ = (ID+D) * FB$/person/year

<u>where</u>:

FB$ = Fringe Benefit Dollars
FB$/person/year = Factor Calculated from Normalized Company Data

Mr Pels stated that the dollars represented by ID$ and FB$ account for 80% or more of the Indirect dollars for Engineering and Manufacturing pools. The Indirect Labor dollars and Fringe Benefit dollars are variable with headcounts which vary to a great degree with business base. The remainder of the overhead was fixed/semi-fixed costs. These include facilities, depreciation of capital equipment and buildings, taxes, utilities, materials, etc. (See Table 2 - portions of overhead).

Total Indirect dollars can be calculated by regressing the Total Indirect dollars against the sum of Indirect Labor dollars plus Fringe Benefit dollars for the Engineering and Manufacturing pools.

OH$ Total = f (ID$ + FB$) (each year's data was one data point)
OH Rate = OH $ Total/DL$ (Base $)

Some of the fixed portions of overhead, e.g., depreciation, were estimated separately using company data and algorithms and cross checked against the fixed portion of overhead estimated by the OH $ Total Cost Estimating Relationship (CER).

The material overhead model was developed by regressing Material Indirect Headcount against Material Base dollars.

Material Indirect Headcount (MI) = f (Material $ Base)
Material Indirect $ = $/person/yr * MI

FB$ = FB$/yr/person MI

Total Material OH $ = f (ID$ + FB$)

Material OH Rate = Total Material OH$/Material Base $

The G&A overhead model was developed by regressing G&A Indirect Headcount, against the Total Direct and Indirect Headcount.

G&A Indirect Labor (GAIL) = f (Total D + ID)
where:

G&A Indirect Labor (GAIL) = G&A Indirect Headcount

Total D+ID = Total Direct and Indirect Headcount (Engineering, Factory and Material Pools)

GAIL$ = GAIL * GAIL salary/person/yr
FB$ = (GAIL) * FB$/person/yr
G&A$ = f (GAIL $ +FB$)
G&A OH Rate = G&A$/G&A Base

Note that these are examples of a general form that could be used to develop specific company overhead models. They may require changes due to differences in contractors' accounting systems.

2.2.1.2 NAVAIR - MACRO MODEL

In 1983, Mr Tom Gilbride of the NAVAIR Research and Methods Section, Cost Analysis Division (AIR 5243) developed macro overhead models for manufacturing, engineering, material, and G&A. The direct and indirect cost experience, from Plant-wide Data Reports (DD 1921-3), of 15 major contractors was analyzed. Data from prime manufacturers of aircraft, missiles, and associated subsystems, covering the period 1975-86, was used in the analyses. Before the analyses could be performed, the data had to be normalized to constant year base dollars. Mr Gilbride found that inflation "does not impact equally on direct and indirect cost because of the mixes of effort in each. Overall, in the data's time period inflation had a greater impact on indirect expenses. The disparate impacts of year to year direct and indirect inflation costs were removed with the most appropriate contractor and NAVIAR developed escalation indices. A separate index was used on each element of direct and indirect expense."

Figures 2 thru 5 show the results of the analyses. Business Base Change (x-axis) was defined as the resulting yearly change in direct cost base from one year to the next, after adjustments for inflation. Overhead Change (y-axis) was defined as the percentage change in overhead rate associated with yearly business base change. Mr Gilbride's study listed the steps required to make adjustments to an individual overhead rate due to changes in its corresponding business base. The list of steps follows:

1. Adjust the individual direct cost base to reflect the business base cost change.

2. Remove the effects of inflation from the adjusted business base.

3. Determine the percentage change in the adjusted business base from its corresponding previous year's business base.

4. Select the appropriate rate adjustment formula and develop the corresponding overhead rate adjustment factor.

5. Use adjustment factor to calculate revised overhead rate.

6. Calculate adjusted overhead costs.

7. Apply appropriate inflation rate factors to adjusted direct base and overhead costs.

8. Calculate new overhead rate.

Figure 2

MANUFACTURING OVERHEAD / BUSINESS BASE CHANGE

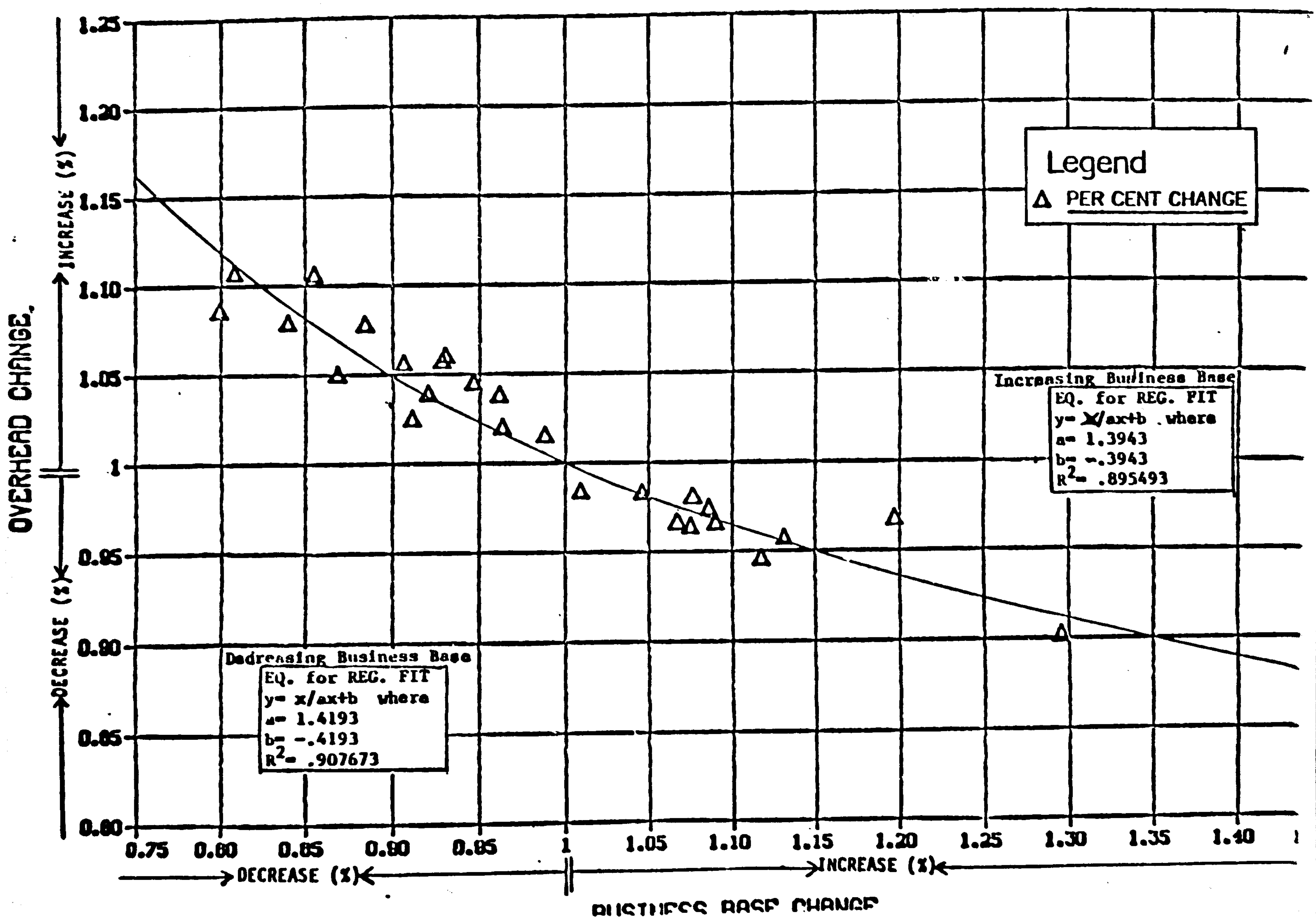


Figure 3

ENGINEERING OVERHEAD / BUSINESS BASE CHANGE

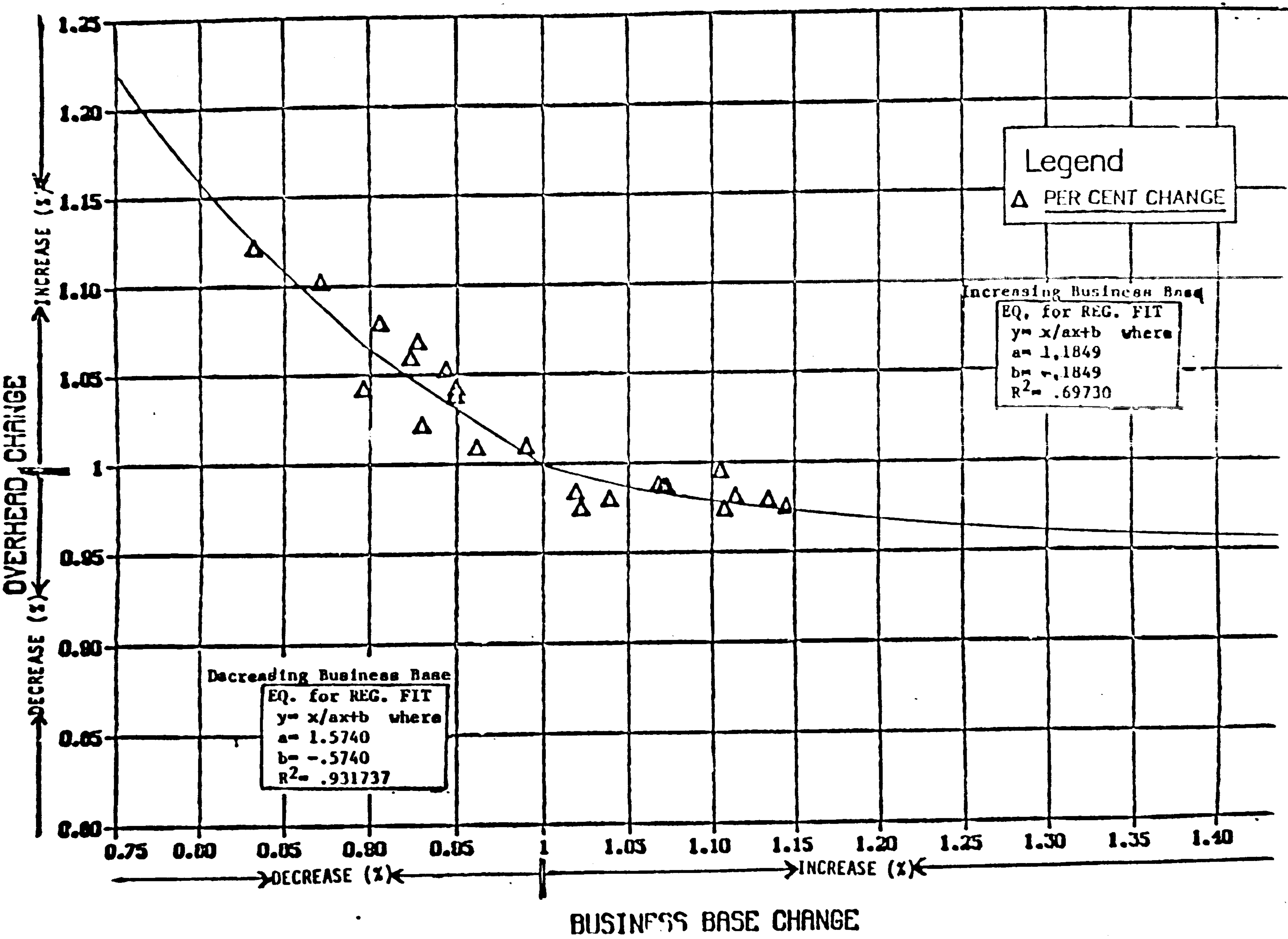


Figure 4

G AND A OVERHEAD / BUSINESS BASE CHANGE

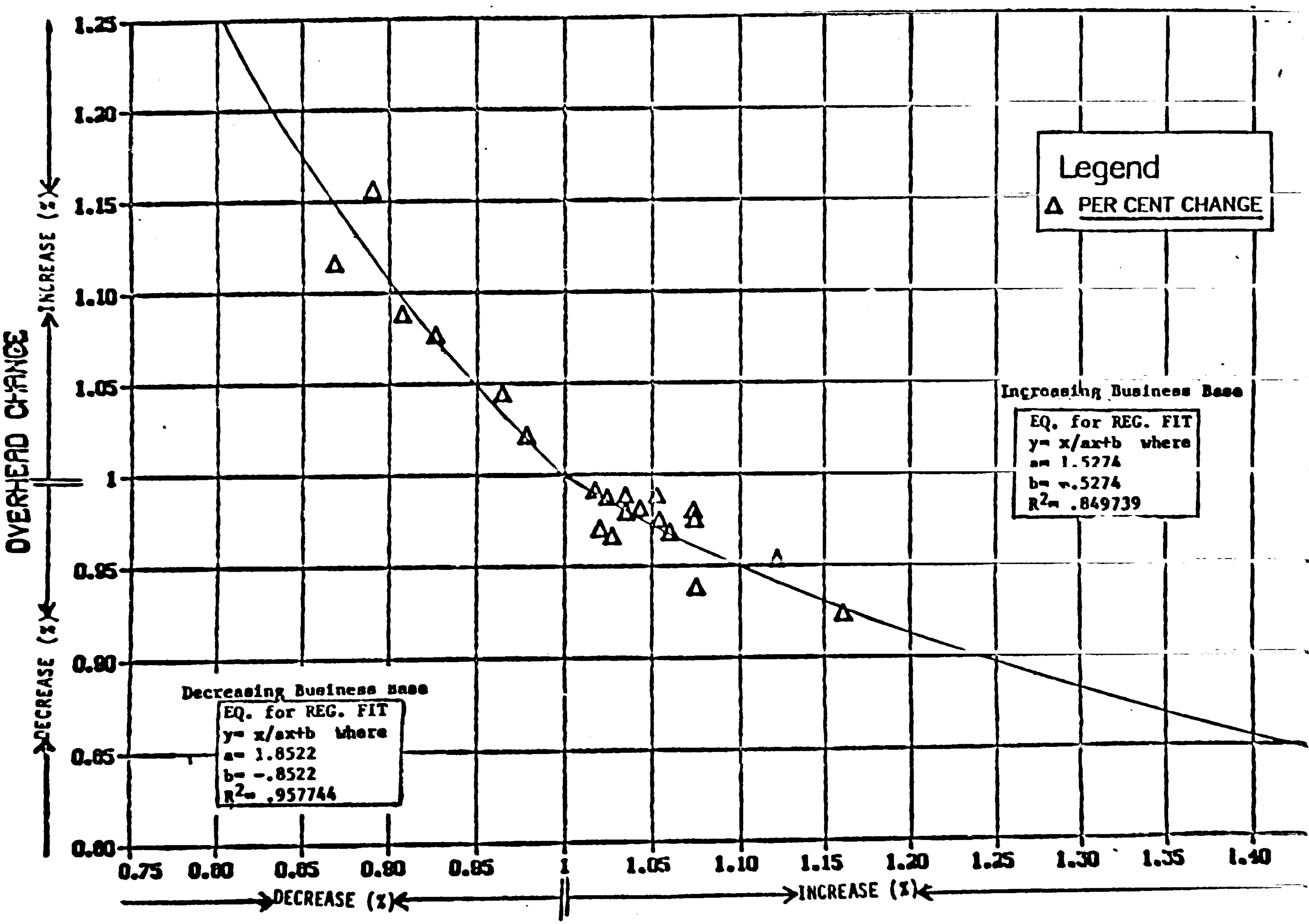
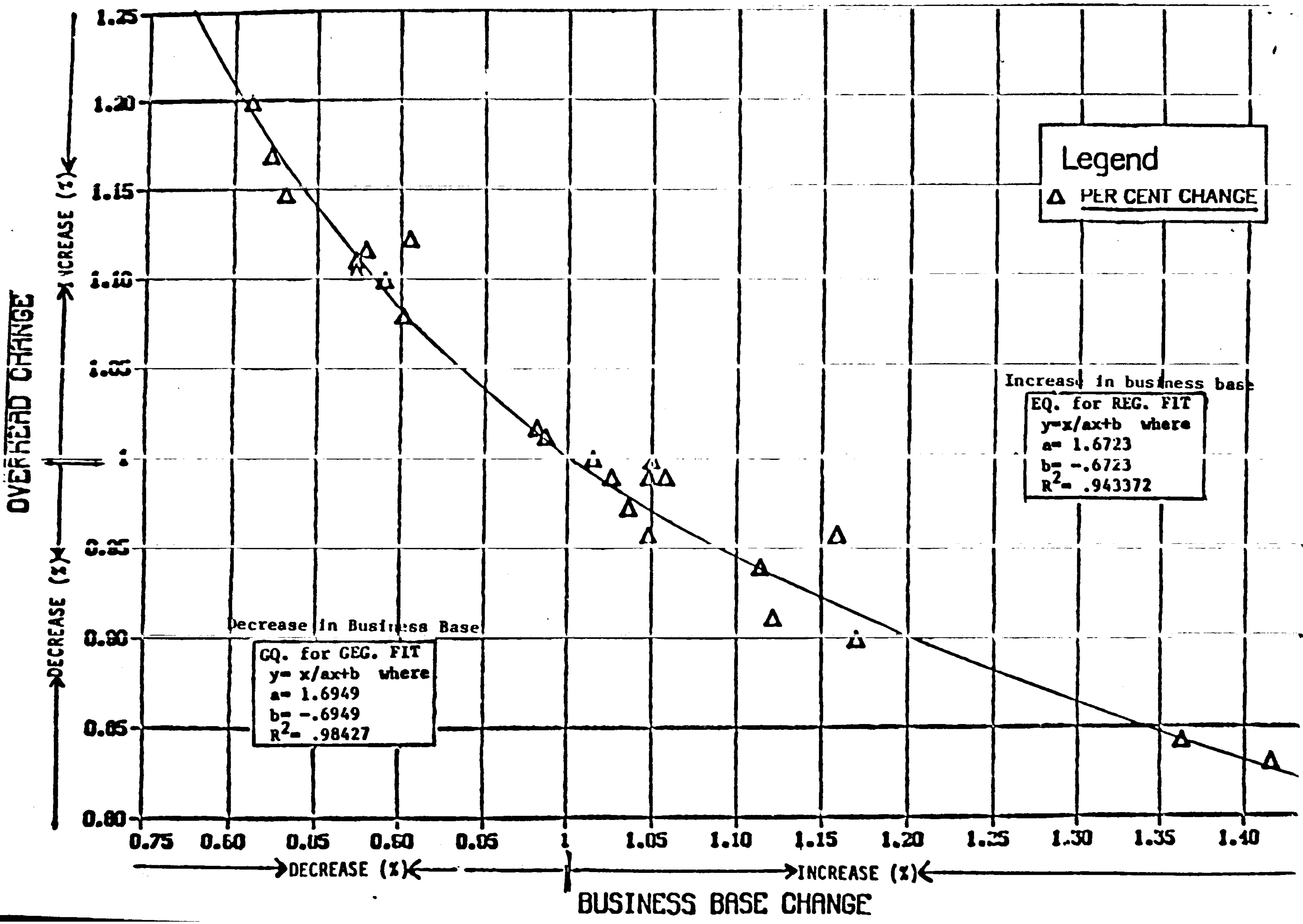


Figure 5

MATERIAL OVERHEAD / BUSINESS BASE CHANGE



2.2.1.3 THE BALUT MODEL

The Office of the Secretary of Defense Program Analyses and Evaluation (OSD PA&E) funded the Institute for Defense Analyses (IDA) to develop an aircraft repricing model which took plantwide business base changes into account. The research was led by Dr. Stephen J. Balut. He has been researching the impacts of business base changes on overhead since 1981. The approach Dr. Balut employed to develop the models for PA&E is best explained by Dr. Balut himself. The following is an excerpt from A Method for Repricing Aircraft Procurement Programs:

Approach (1)

> The approach is an extension of the price improvement curve method that explicitly takes the fixed component of cost into account when repricing. This is accomplished through separate estimation of the fixed and variable components of cost, which are then combined to obtain the total cost. This approach requires fixed costs to be distinguished from other costs. This separation has been accomplished at the plantwide level for several aerospace firms, and because overhead is allocated to programs for cost recovery purposes, it is legitimate to apply the same separation to the cost of individual programs within the plant.
>
> Once fixed costs have been determined and removed, variable costs for a sequence of system lots can be used to develop another variant of the learning curve, known as the variable cost progress curve, despite the fact that the variable costs for the lots are not observed. This curve has the same simple form as the price improvement curve, but it relates unit variable cost to cumulative quantity. It can be used to estimate the variable costs for alternative procurement quantities, and then the fixed costs can be allocated to systems within the periods in which they are produced in a manner similar to that used to allocate overhead to contracts.
>
> The approach involves the following steps:
>
> - separating the contractor's plantwide business base into fixed and variable parts,
> - applying plantwide relationships to contract (e.g., airframe) costs to separate annual expenditures into fixed and variable components,
> - fitting a power function (variable cost progress curve) to the variable part of contract costs,
> - estimating contract variable costs for the new annual procurement quantities with the variable cost progress curve, and
> - allocating fixed costs to the contract in a manner similar to that used by accountants to allocate annual plantwide overhead costs.
>
> The method is most appropriately applied to the major contracts (e.g., for components, such as airframes and engines) of an acquisition program.

(1) Stephen J. Balut - Institute for Defense Analyses, Thomas R. Gulledge - George Mason University, Norman Keith Wormer - University of Mississippi, A Method for Repricing Aircraft Procurement Programs, March 1988

The contractors analyzed were:

Aircraft

McDonnell Douglas Aircraft Company (MCAIR), St. Louis
General Dynamics, Fort Worth Division
Grumman Aerospace Corporation, Bethpage
Northrop Aircraft Division, Hawthorne
Voight LTV, Texas Division
Lockheed, California Company

Helocopters

Sikorsky Aircraft Division

Engines

General Electric Aircraft Engine Business Group
United Technologies Pratt & Whitney

Radar/Missiles

Radar Systems Group, Hughes Aircraft Company
Missile Systems Group, Hughes Aircraft Company

Detailed contractor data covering the 1960's through 1987 was obtained. Each company's specific indices and adjustments were used to normalize the data and develop the models. The models were adjusted for changes in contractor accounting systems. Outlay profiles were obtained from Cost Performance Reports (CPRs) and company data.

The overhead portions of the model were usually of the form:

OH = f (a, L, C)

where:

OH = Total Overhead Dollars

a = A Fixed Constant

L = Total Factory Labor (either Direct or Direct plus Indirect)

C = Total Capital (Facilities, Capital Equipment etc)

The fixed portion of overhead is related to the parameters a and C. The model uses the overhead CERs to calculate the plantwide overhead for future calander years. The CERs were derived using regression analysis on the data points of plantwide calendar year historicals.

The IDA data and model structure could be used to develop prime and major subcontractor (if a teaming arrangement exists) overhead models for factory, engineering, G&A and material. The current IDA models estimate total overhead dollars. The current models could be used to estimate the overhead impacts of business base changes on vendor CFE, major subcontracts, minor subcontracts and intercompany work orders. For these cost elements, a detailed breakout of overhead (i.e. factory, engineering, etc) is unnecessary.

2.3 LEARNING CURVE WITH RATE ADJUSTMENT

This method uses the standard learning curve ($Y=AX^B$) with the addition of a multiplicative rate parameter (Q^R) where Q is the annual lot quantity and R is the LOG (rate slope)/LOG 2. A 90% rate slope will cause a 10% reduction in Y, solely due to rate effect, when production rate doubles. Figure 6 depicts the $Y=AX^B$ learning curve. Figure 7 shows a learning curve with rate adjustment ($Y=AX^BQ^R$) when production rate is increasing in each consecutive lot (ramp-up). Figure 8 shows a learning curve and learning curve with rate adjustment used to estimate the same data. Figure 9 shows the impact of a production rate ramp-up (lots 1 to 3) followed by consecutive production rate decreases (lots 4 and 5) on a $Y=AX^BQ^R$ function.

This methodology can be used to estimate any costs which have fixed cost inherent in them. Any cost elements which have setup, SE/PM, EOQ impacts, overhead and any of the other fixed costs listed in Tables 2 and 3 are candidates for this methodology.

I found that this methodology is well suited for estimating fabrication for aircraft and missiles/avionics, raw materials/purchased parts (RM/PP) for aircraft, bills of material for avionics and missiles, and CFE/purchased equipment (PE) for aircraft. Analysts should only use this method at a weapon system or subsystem macro level when there is not enough time, resources and/or data to break out the fixed costs in a discrete manner.

The accuracy of this methodology decreases when being used to estimate elements which include overhead because it is system specific and does not take into account plant-wide business base changes. The rate variable only accounts for production rate changes of the system being estimated by the algorithm. An aircraft estimator who does not have the time and/or data to break out the SE/PM data and fixed portions of overhead for every piece of CFE may have no other choice. Some aircraft estimates have one hundred or more CFE/PE items which are separately estimated.

The analyst may be fortunate to have the time and resources to attempt to break out the fixed costs and model plant-wide overhead for one or two high cost items i.e., radar, Forward Looking Infrared (FLIR), but to do this for every piece of CFE/PE would be impractical.

In general, the more macro the estimating done with this methodology the more opportunity for error due to the fact that some specifics may be ignored. However, this weakness applies to almost any estimating approach, regular learning curve analysis included.

Another problem with this methodology is the possibility of multicollinearity. Production rate (Q) normally increases as cumulative quantity increases. The two therefore are usually highly correlated and may produce multicollinearity when the historical data is regressed. Multicollinearity occurs when an independent variable is a linear combination of the others, i.e., the independent variables are not independent of each other.

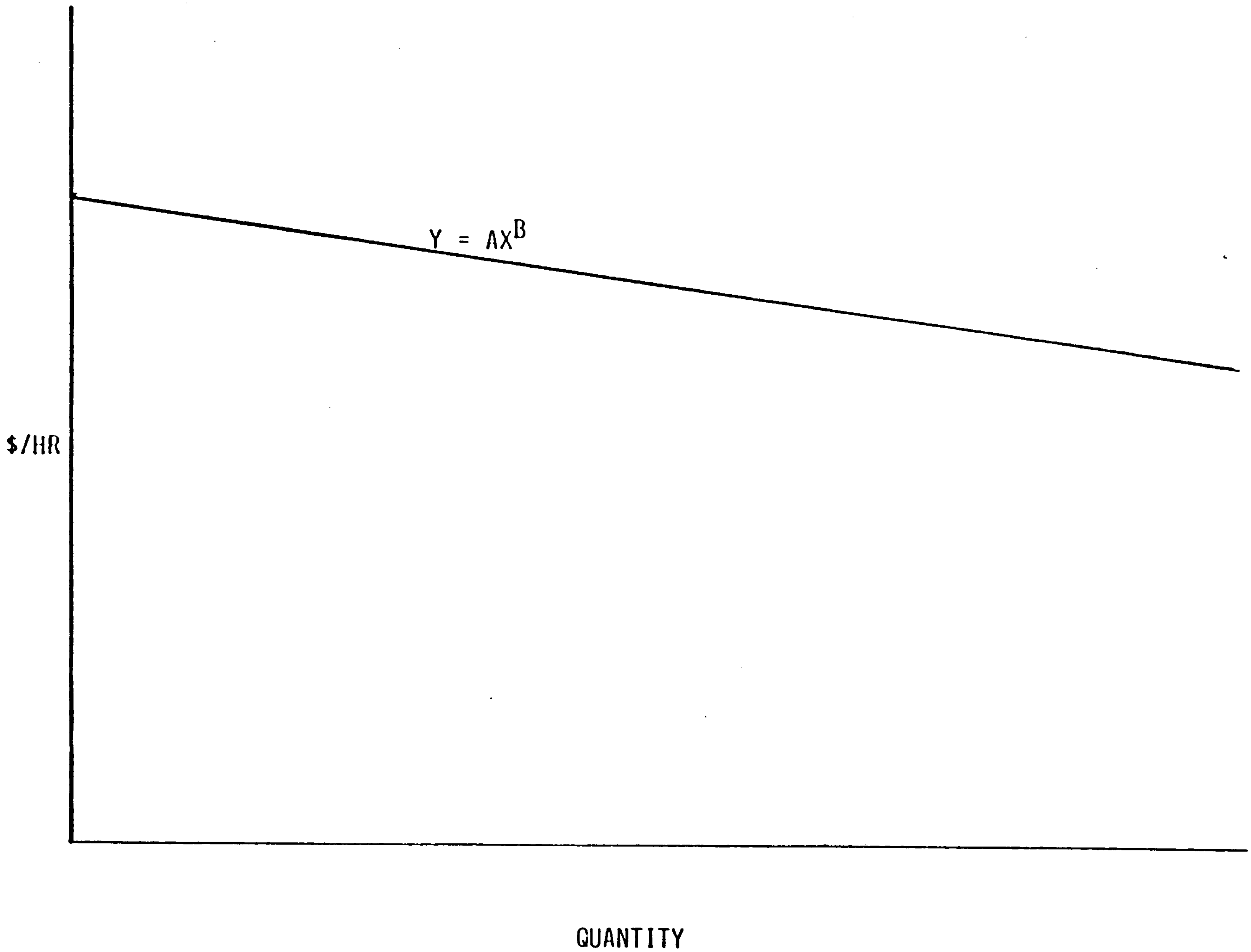


Figure - 6 Standard Learning Curve

$$Y = AX^B Q^R$$

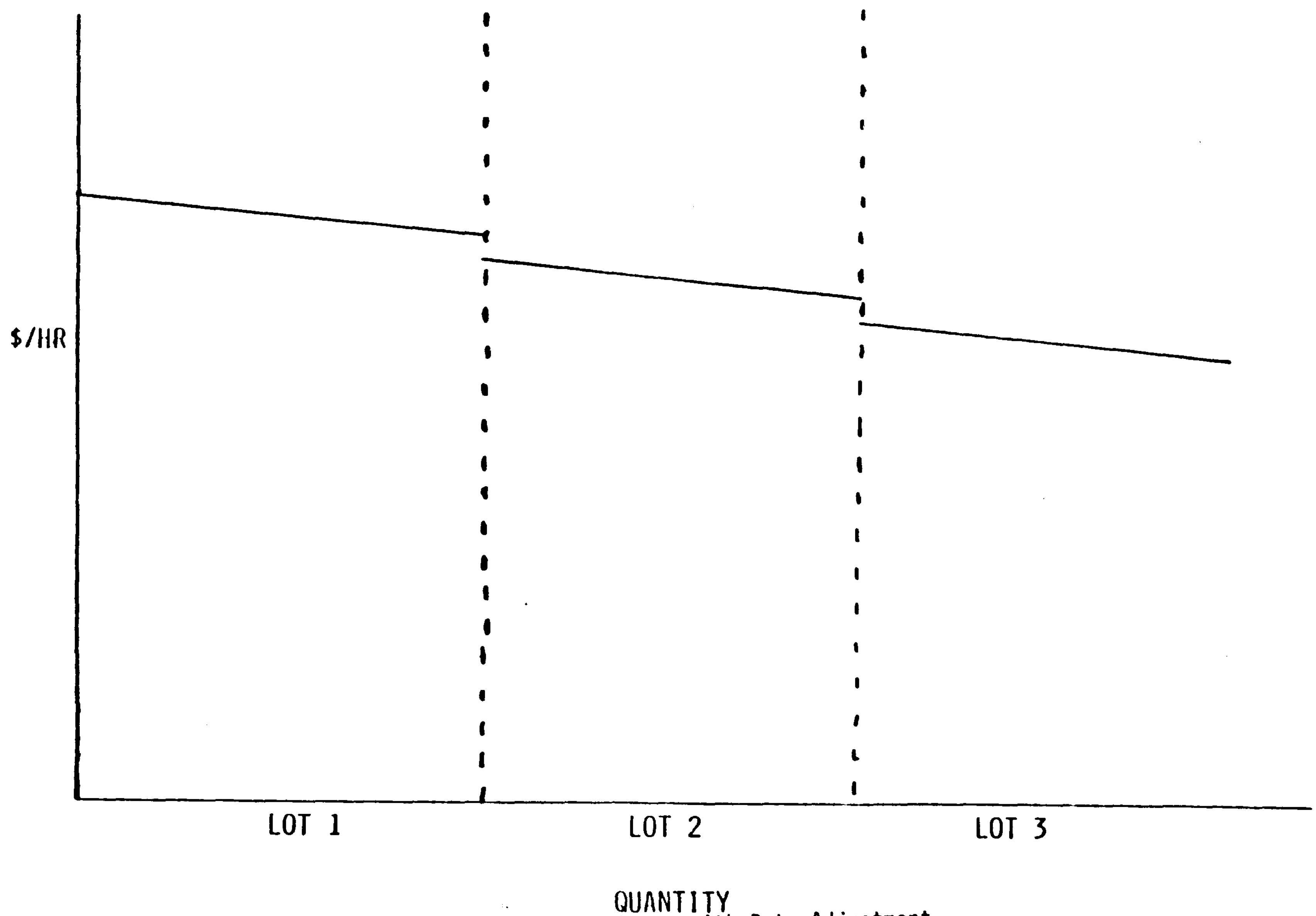
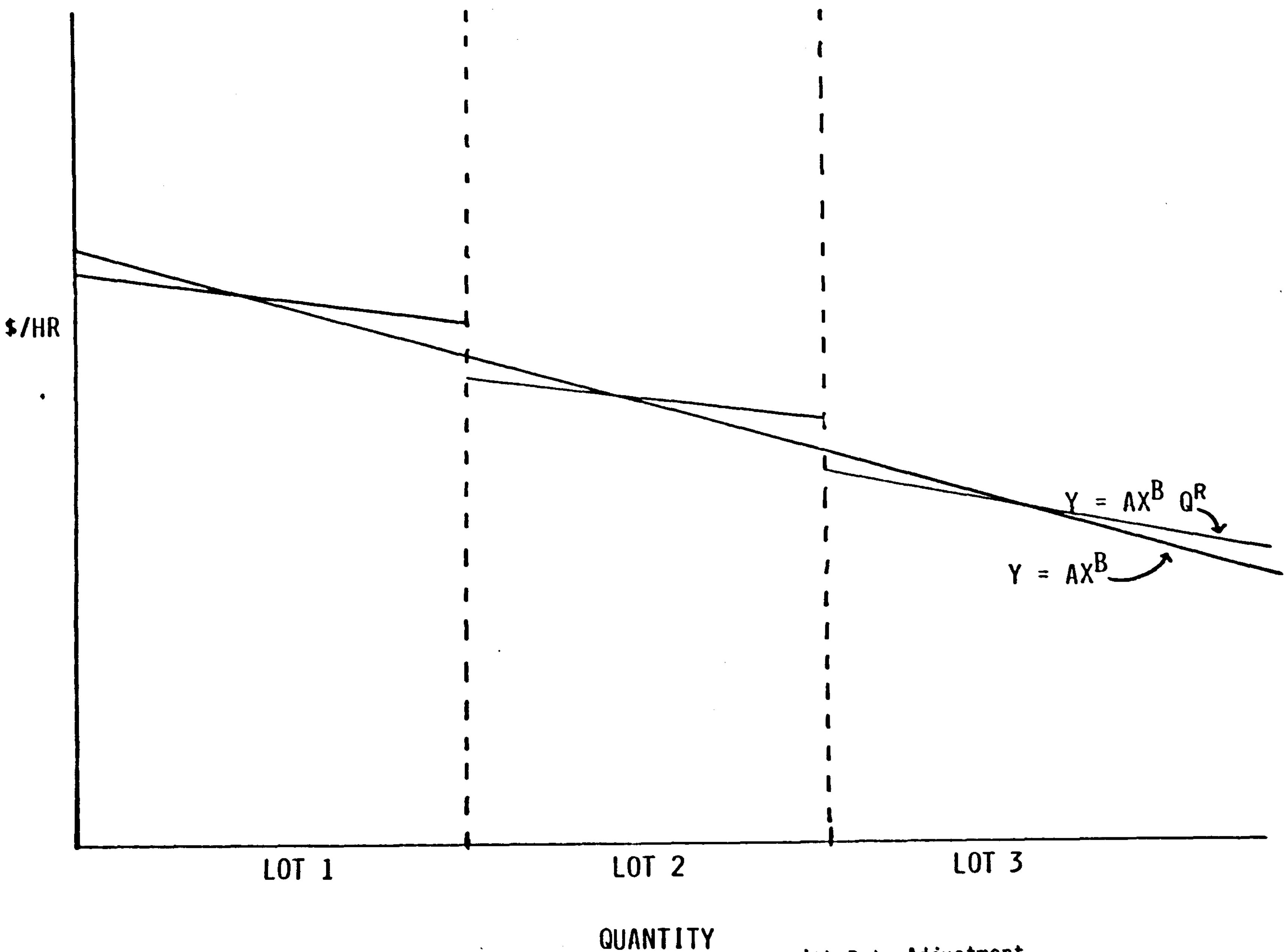
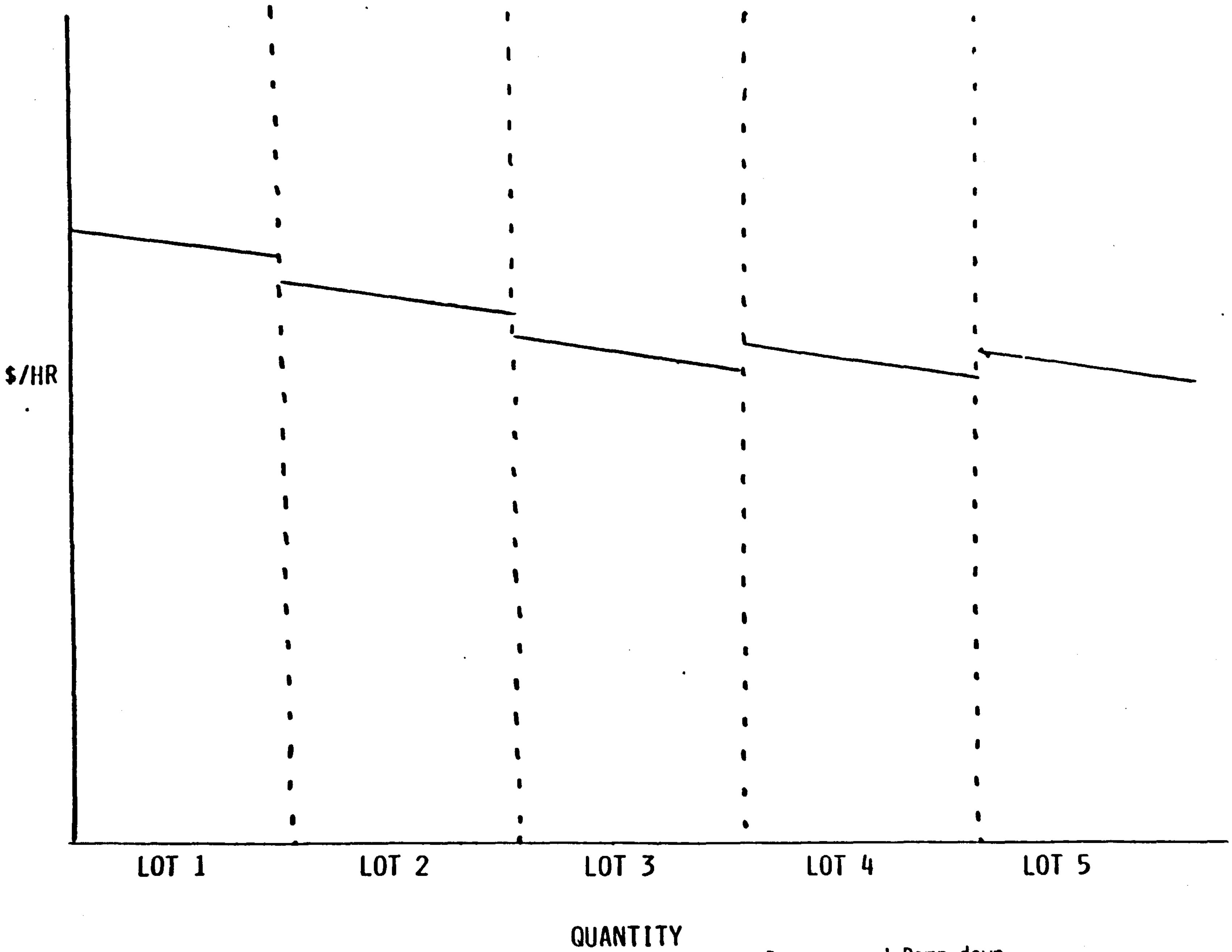


Figure 7 - Learning Curve with Rate Adjustment



Fugure 8 - Learning Curve and Learning Curve with Rate Adjustment



Fugure 9 - Learning Curvw with Rate Adjustment - Ramp-up and Ramp-down

"Multicollinearity can cause an imprecision in the estimators (coefficients): they have a large variance and consequently are not very reliable. The existence of multicollinearity does not mean that the estimators of the coefficients are biased." (1)

Multicollinearity does not effect any of the assumptions making ordinary least squares a best linear unbiased estimator (BLUE).

"Multicollinearity refers to a situation where, because of strong interrelationships among the independent variables, it becomes difficult to disentangle their separate effects on the dependent variable. The question is how strong these interrelationships have to be to cause a problem. Thus, with multicollinearity, the problem is one not of existence or nonexistence but of how serious or problematical it is." (2)

"Multicollinearity comes in degrees and may or may not in particular cases prove troublesome. There is, however, a recognizable set of symptoms for the classic case of multicollinearity: a large coefficient of determination (R^2) accompanied by statistically insignificant estimates of the coefficients of the independent variables. What this means is that certain (at least one) of the independent variables appear to influence systematically the dependent variable (as indicated by the high R^2), but we cannot tell which ones." (1)

"More formally, the problem is that a high degree of multicollinearity results in large variances for the estimators of the coefficients; as a consequence the t ratios tend to be very low. Recall that a large variance (or a small t ratio) implies that a 95 percent confidence interval for the corresponding parameter will be relatively wide; a large range of values of the parameter, perhaps including the value zero, will be consistent with our interval. This suggests that, even if the corresponding independent variable has an important effect on the dependent variable, the multicollinearity problem may lead us to believe that its effect is insignificant." (1)

Another way to test for multicollinearity is to regress the independent variables against themselves, (i.e. Q=f(X) X=f(Q)). The presence of a high R^2 is indicative of multicollinearity. An F test can be performed on this R^2 to determine if multicollinearity is statistically significant.

Mr. John Dorsett of the NAVAIR Cost Analysis Division has developed a regression program called "Rate" that includes this test. The analyst builds a data file which contains the number of data points, the first and last unit of each lot and the unit average value of each lot. The program calculates the A, B, and R values; the statistical measurements (R^2, $\bar{R}^2$, F Ratio, Standard Error of Estimate (SEE) etc); regresses each independent variable against the other; and calculates their R^2 and F test on the R^2.

(1) Harry H. Kelegian, Wallace E. Oates, Introduction to Econometrics-Principles and Applications,

(2) G. S. Maddala, Econometrics, McGraw Hill Book Company, Copyright 1977

If a multicollinearity problem exists, there are some techniques that can be attempted to try to solve the problem while still keeping both variables (X and Q). Three possible solutions are presented.

The first is to collect more data. This solution is one that is rarely available in the weapon system costing field. The analyst is usually starting with all the data points available for a particular system or subsystem.

A second solution is to use extraneous estimates. Simply pick a rate slope based analogous data and/or the estimator's experience and then normalize all the Y values for production rate, i.e. divide each Y by Q^R. Then regress the normalized Y's against AX^B ($Y/Q^R=AX^B$) to find the learning slope for the historical data given the specific rate slope chosen. Further information concerning the choice of a rate slope is presented later in this section. Mr. Dorsett has also developed a software program called "Rate 2" that allows the analyst to pick a rate slope and then determine the learning slope. The program runs off the same data file used by the previously described "Rate" program.

The third solution to the multicollinearity problem is the use of Ridge Regression to estimate the constant (A) and coefficients (B&R). Mr. Carl Wilbourn of the Naval Center for Cost Analysis (NCA) has used this approach extensively. The Ridge Regression program used by Mr. Wilbourn displays a ridge trace at different K values with the statistical analysis of the historical data. Hoerl and Kennard (1) suggest starting with very small values of K, (i.e., .01) and increasing it until the resulting estimates of the regression parameters are "stable" or do not vary much. This point of stability, and its corresponding K value, can be clearly seen on a ridge trace.

(1) A. E. Hoerl and R. W. Kennard, Ridge Regression: Biased Estimation for Non-Orthogonal Problems, Technometrics, 1970.

I was the lead cost analyst on the F/A-18 from 1985 to 1988. During this time, total program quantities went from 146 to 92 and were projected to go below 72. Some projections had to be made to the 36 quantity level. Adjustment for rate effect had to be an integral part of any F/A-18 estimating methodology. Some subjective rules of thumb developed from this experience are as follows:

Because of multicollinearity and data problems, the resulting coefficients from the regression of historical data should never be used blindly. An acceptable rate slope range for most systems/subsystems (CFE, PE, Bill of Material, etc) is in the 85 to 100 percent range depending on plant-wide business base, manufacturing process, SE/PM data staffing and other considerations. In special circumstances a rate slope as steep as 80% was used. The analyst should, at a minimum, attempt to obtain a qualitative assessment of each company's business base and rate sensitivity before selecting the final slopes. When the coefficients looked questionable, i.e. rate slopes below 80 or above 100, learning slopes above 100 percent etc. and/or multicollinearlity appeared to be problematic, a rate slope was chosen based on analyst judgement and qualitative knowledge of the equipment and company. The "Rate 2" program was then used to determine the learning slope. After analyzing historical data on a large cross section of subsystems an analyst will get a feel for what range the slopes should fall in.

An analysis of contractor quotes for various CFE avionics systems showed SE/PM and data to be between 5 and 20%, depending on the base size, of total recurring flyaway cost. A rate adjustment slope of 95 percent, to at least cover this portion of fixed costs, is not unreasonable or pessimistic.

The rate slope for fighter airframe fabrication, setup plus run, was usually estimated to be in the mid to high 80's. This proved true for both F/A-18 contractors and was also crossed-checked against F-15 data.

The rate slope for RM/PP was usually in the mid to high 90's.

The F/A-18 historical data used to develop the previously stated knowledge/rules of thumb included a period of ramp-up (FY-79 to FY-85, quantities of 9 to 146) and a period of decline (FY-85 to FY-88, quantities of 146 to 92). Most other historical data includes more ramp-up than ramp-down/stretchout of quantities. It is not certain that the slopes determined in ramp-up reflect what will be experienced in ramp-down. The contractors have little incentive to eliminate fixed costs and cut price when they are losing business. More research needs to be performed in this area. The historical data from current and future stretchouts should provide more understanding of the rate effect. The estimator may have to turn to analagous systems, preferably from the same plant, if a number of years of historical data and/or a period of ramp-down are not available on the weapon system to be estimated.

Obviously another drawback in using learning curves with rate adjustment is the need for analyst knowledge of statistical techniques and model building. The selection of accurate slopes requires estimating experience and a knowledge of weapon systems, company business base, manufacturing process, etc. Of course, these same pitfalls exist for learning curve analysis as well as other estimating methodologies.

On a positive note, learning curves with rate adjustment can be built into detailed automated cost models, allowing consistent estimating for quick turn around exercises. They are easy to apply, statistically verifiable, and defendable. When fixed costs can not be broken out and/or estimated separately, the learning curve with rate adjustment is the best alternative.

2.4 CURVE ROTATION

This method rotates the standard learning curve ($Y=AX^B$) to a flatter slope to account for production rate decreases. This has a cumulative effect. The cost in later years is impacted (increased) by the penalty on the first years of the stretchout. The contractor will never recover to the same point on the curve with the original slope even if rate were to increase back to its original peak level. Only a steepening and/or downward displacement of the curve would result in recovery.

This methodology is easy to model and apply, but I believe it suffers from severe problems. The methodology is very judgemental and when performed repeatedly over many different profiles will probably lead to inconsistencies. Because of its nature, curve rotation can not easily be built into an automated model. The analyst must decide where to rotate the curve (at what loss of quantity, 1, 10, etc), the percent of rotation and which curves to rotate. I believe this methodology to be the least preferred of those currently used by the costing community.

3.0 CONCLUSION

It is very important that all program office estimates and ICAs be sensitive to the rate effect. Program offices have always had to deal with varying quantity profiles but ICA teams were usually tasked to estimate one profile. This is no longer the case. Many times, in the Air Force at least, the ICA methodology is accepted by the System Program Office (SPO) and becomes the methodology for estimating budgets. Rate sensitivity will then be required and may even be needed during the ICA's development. For example, the Tacit Rainbow ICA team had the Navy drop out of the program in the middle of the ICA's development. OSD PA&E has now requested the ICA team to cost both quantity profiles, i.e., Air Force Only and Air Force and Navy. Fortunately, Headquarters Air Force Systems Command/Directorate of Cost (HQ AFSC/ACC) had tasked the team to develop a rate sensitive estimate. It is now HQ AFSC/ACC policy to require all ICAs to be rate sensitive. Program offices are also urged to develop and use rate sensitive models for their annual estimates.

Not all of the methodologies described can be used for all programs, given data and time constraints. It is therefore the estimator's responsibility to understand the concepts/methodologies and their limitations and then apply the one(s) which fit their particular program's needs. The analyst should be able to explain and defend the methodologies selected. It is essential that rate sensitivity be built into the estimator's detailed automated cost model from the beginning. Time is not available to develop a new rate sensitive methodology once the requests for stretchout estimates are initiated. Rate sensitivity can not be added as an afterthought. The historical and/or analogous data must be analyzed for rate effect prior to developing an initial estimate.

I have described several methodologies and their uses, yet my intention in writing this paper was to stimulate discussion, thought, research, and cooperative efforts. With the enactment of the Graham-Rudman-Hollings Bill and the affect this will have on the present and coming years this subject of rate sensitivity is certainly timely. I hope that each analyst and the costing community as a whole will pursue further research, develop new and better methodologies for accounting for rate sensitivity and adjust to an ever changing DOD environment controlled by budget constraints.