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Functional Cost Estimating Techniques Applied to Operational Flight Trainers

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FUNCTIONAL COST ESTIMATING TECHNIQUES APPLIED TO OPERATIONAL FLIGHT TRAINERS

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

> "Cost estimating is of prime importance to effective planning for future trainer acquisitions and managerial control of current acquisitions. Of major importance are those cost estimates which provide the basis for input to the budget review cycle for the acquisition of training equipment."[1]

Cost estimating involves the process in which projections are made concerning the expenditure of effort and the cost of materials to achieve some stated or implied objective. Estimating the cost of flight trainers in the NAVTRAEQUIPCEN training command presents a unique problem. Within the training command the estimating process usually involves judgements made by a single estimator or a team of estimators. There is an inclination on the part of the estimator to underestimate the scope of effort required to achieve a given objective at some future date. This stems in part from the fact that many of the difficulties associated with achieving certain objectives are not fully understood by the estimator or estimators due to their lack of knowledge in specific cost estimating techniques. Other factors which increase the uncertainty in estimating the cost of new systems are as follows:

1. Training requirements for a new system not adequately defined. (In this case a design approach cannot be established with reasonable confidence.)

2. Lack of data on the system being simulated.

3. Difficulty in documenting the requirement to a degree that prevents increase in scope as one proceeds from the time the estimate is developed until the project is implemented.

4. Problems of predicting inflation.

This research paper presents and investigates functional cost estimating techniques applied to the Operational Flight Trainer (OFT).

The objectives are to examine the system design Work Breakdown Structure (WBS) of the Operational Flight Trainer (OFT) which consists of the following elements and to show how it can be used to estimate cost. Those elements that cannot be given a point or interval estimate will be given a methodology for establishing a range of values.

1. Student station or trainee station

2. Instructor station or instructor display system

3. Motion system or motion platform

4. Visual system

5. Computer system software

6. Computer system hardware

7. System integration

The assumptions of this research paper are that:

1. An Operational Flight Trainer (OFT) device will have from one to four trainee stations.

2. Each Operational Flight Trainer (OFT) device is unique and they are not mass produced.

3. All experimental data used in this research paper are random samples from the population being studied and the estimators of the population possess all the desirable properties such as unbiasedness, consistency, efficiency, and sufficiency.

4. Visual system, computer software, computer hardware system(s) and motion system(s) costs are independent of each other. In other words the approach used to realize these subsystems in no way affects the approach to be used to build another subsystem, so that any approach chosen would be able to interface with the other approaches.

5. Instructor station cost is dependent upon student station cost and both are independent of the other subsystems costs.

6. The more complex the system design hardware, the higher the cost the system integration Work Breakdown Structure (WBS) element will be. The hardware subsystem complexity is measured by the estimated total cost of that subsystem.

CHAPTER II

FLIGHT SIMULATOR TRAINING AND TRAINERS

Before attempting to estimate the cost of a military flight simulator trainer, it must be defined. Whenever a flight training situation exists, there arises the problem of determining what trainer or combination of trainers will best meet the needs of the users. Sometimes this problem is assumed by the sponsor as to what is acceptable to meet the requirements. At other times the problem of training is determined by the NAVTRAEQUIPCEN. All of this is handled through a Military Characteristics (MC) document [2] that identifies the source of the training requirement, provides an analysis of the training situation, identifies and recommends instructional media, sets forth the Integrated Logistics Support requirements, and provides an evaluation/introduction/validation plan. It is prepared in close coordination with the Fleet Project Team.

The trainers that are usually considered are the Cockpit Familiarization Trainer (CFT), the Cockpit Procedures Trainer (CPT) and the Operational Flight Trainer (OFT) without visual and motion, and the Operational Flight Trainer (OFT) with visual and motion. Figure 1 shows that these different trainers are separated by complexity of training tasks which in turn affects their cost. Also, within each type of trainer there is a cost range depending upon the number and complexity of training tasks desired.

The Cockpit Familiarization Trainer (CFT) incorporates facsimiles of the flight stations of a specific aircraft. It is primarily for the use of pilots, other flight officers and flight engineers who are transitioning to a new type aircraft, and for refresher training for experienced personnel. This device will normally be used to prepare trainees for entry into an Operational Flight Trainer (OFT) or into the aircraft. It will be used to facilitate the learning of the location of the various controls, instruments, switches, and lights in the cockpit and to learn repetitive tasks such as checklists and normal and emergency operating procedures. The trainer may also be used in the classroom as a teaching aid. The controls, switches and instruments are not connected for response to trainee inputs; however, all annunciator lights are operable from the instructor's panel for demonstration purposes.

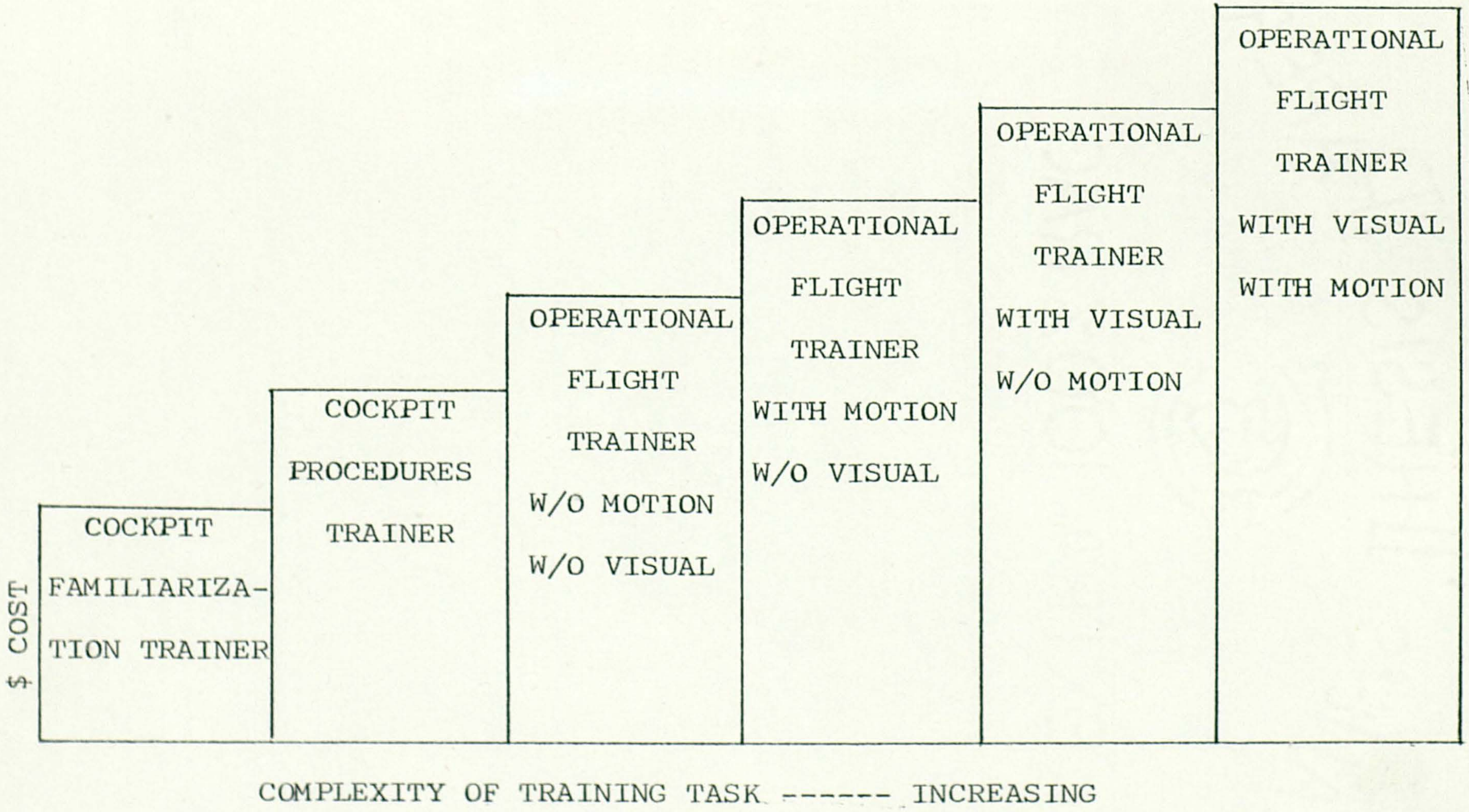


Fig. 1. Flight Simulator Training

The Cockpit Procedures Trainer (CPT) generally incorporates a replica of a specific aircraft flight station and air operator/instructor station(s). It is used by pilots and aircrewmen transitioning to a new type aircraft, or undergoing basic training, and provides cockpit familiarization and training in powerplant and systems procedures of normal, alternate and emergency types. The applicable aircraft instruments and other indicators are activated to respond appropriately to trainee control inputs. Exact dynamic simulation of all functions is not required. This system is illustrated in Figure 2.

The Operational Flight Trainer (OFT) is used to teach flight crews the operational use of all controls and instruments applicable to ground operation, takeoff, landing, normal flight, various in-flight maneuvers, communication/navigation procedures, emergency operations, and such subsystems procedures as are under the control of the personnel being trained. A generalized Operational Flight Trainer (OFT) is illustrated in Figure 3, and an Operational Flight Trainer (OFT) with simplified visual is illustrated in Figure 4.

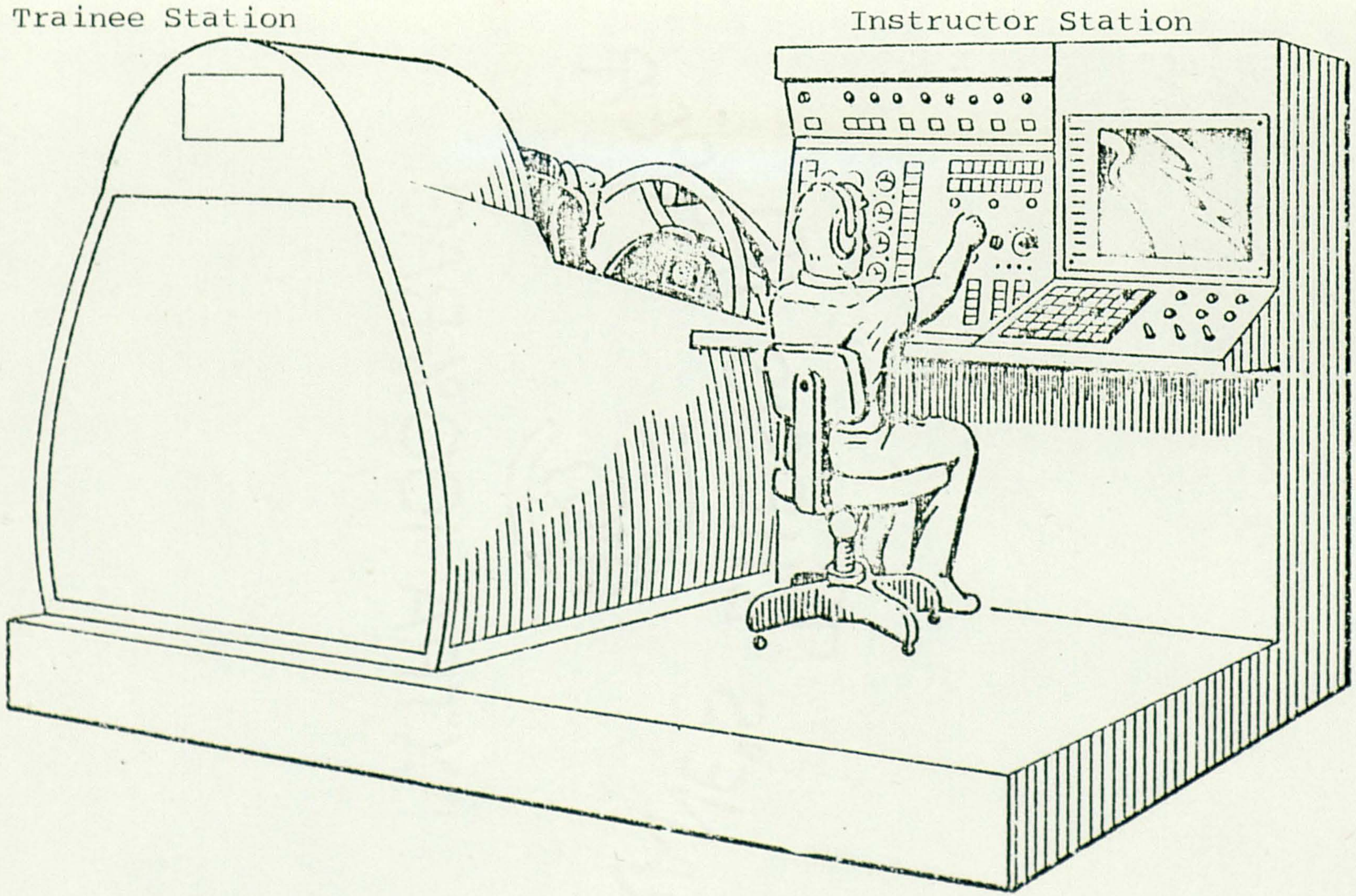


Fig. 2. Cockpit Procedures Trainer (CPT)

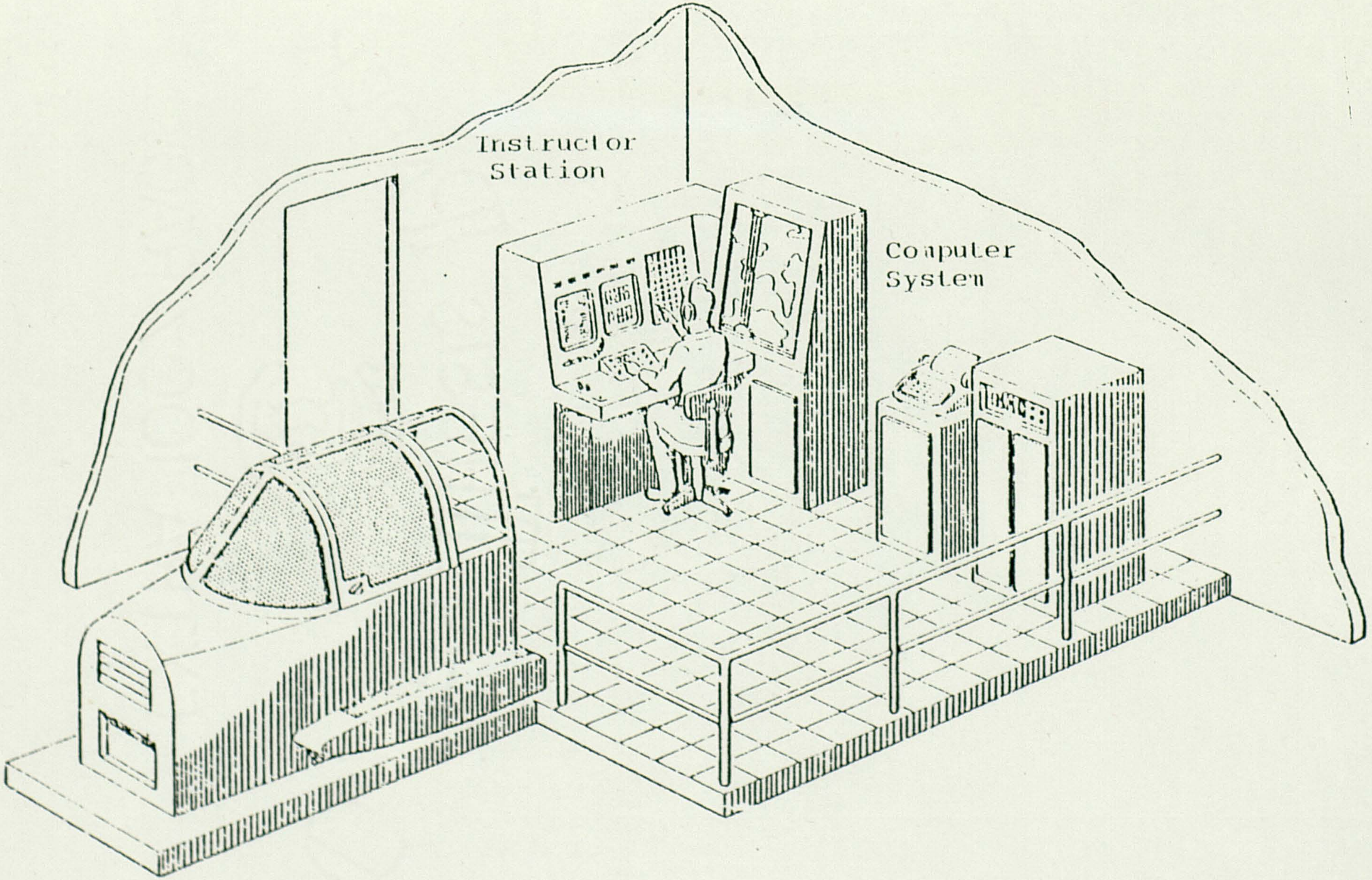


Fig. 3. Generalized Operational Flight Trainer without visual and motion

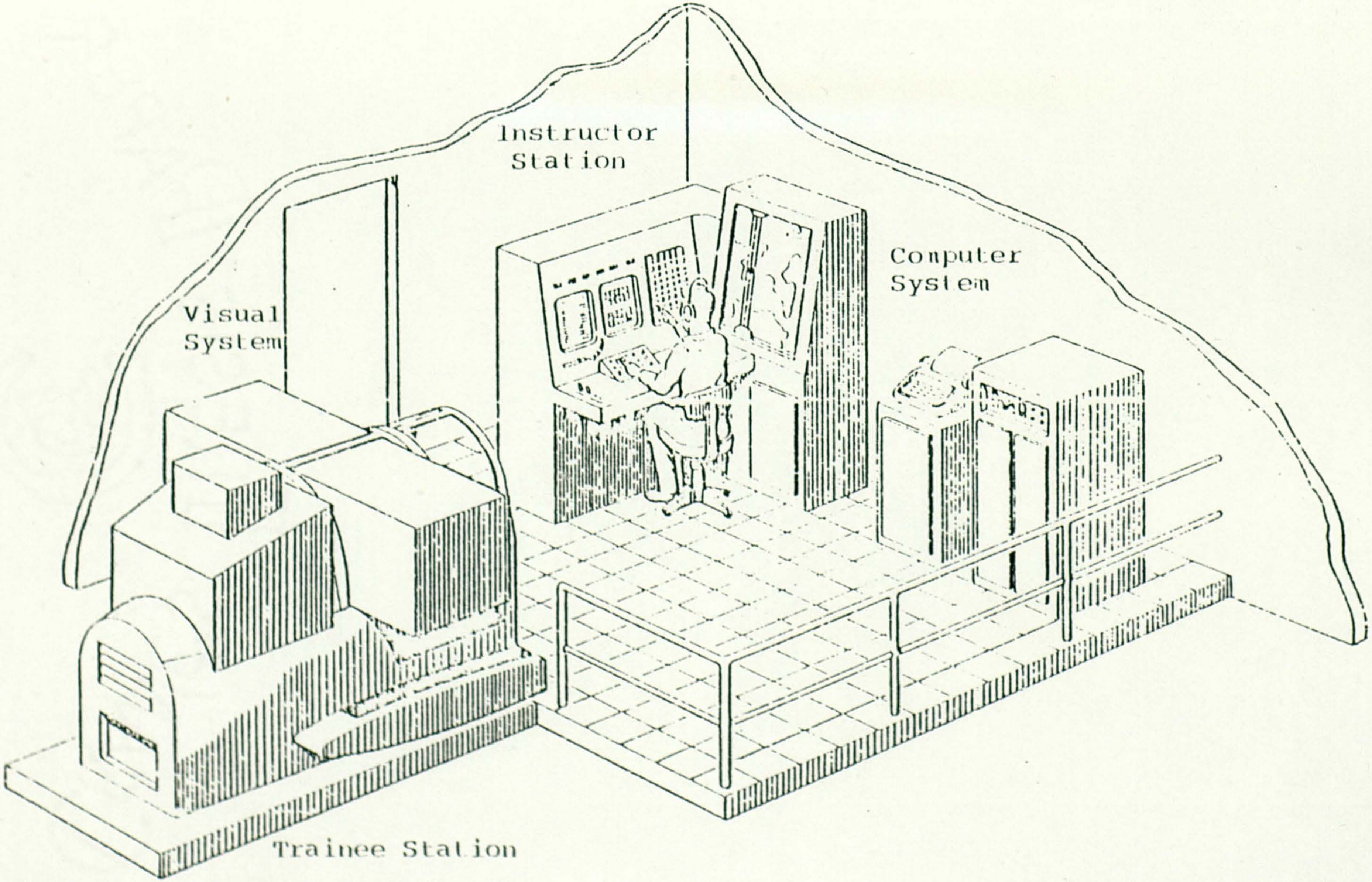


Fig. 4. Operational Flight Trainer with simplified visual

CHAPTER III

PROBLEMS OF COST ESTIMATING

Cost estimating is divided into three different types. [3] Type 1 is a planning estimate. This estimate is for "out" year procurements that are used to define alternate design approaches prepared as an element of a mini-project master plan. "Out" years are defined as beyond the budget year. A mini-project master plan is a technical procuremement plan which includes cost estimates, lead time, functional baseline, etc. A Type 1 estimate utilizes a Work Breakdown Structure (WBS) to estimate a second or third level cost. These estimates are the estimates that are most likely to be requested on a "crash" basis, utilizing limited data and may require research and development funds. Despite these facts, these cost judgements may result in important budgetary decisions. The quality of the estimate and the technique used depend almost entirely upon the data base available to the estimator. If the estimator is able to draw an analysis with other systems, then the uncertainty of the estimate is reduced. If it is a totally new system the estimate may consist largely of expert opinions, and the uncertainty of the estimate is high.

Type 2 is a detailed estimate prepared as an element of the project master plan. The project master plan is a detailed technical procurement plan intended for prosecution of an acquisition task. It serves as a basis for NAVTRAEQUIPCEN acceptance of an acquisition task and when coordinated and approved by the appropriate sponsoring agency, becomes a commitment of the Center's resources to accomplish the task. A Type 2 estimate utilizes a Work Breakdown Structure (WBS) to estimate to the third and fourth levels. It should not require research and development, which would have been identified in previous estimates, and is based on the best available data backed with sound rationale.

Type 3 is a reprocurement estimate. This is an estimate for an identical or similar device previously procured. It may or may not utilize a Work Breakdown Structure (WBS). This estimate utilizes the analogy type estimating techniques with adjustment factors to reflect the projected inflation rate. The accuracy of this estimate should be approximately $\pm$ 10 percent.[4]

Of the three methods, Type 1 is the estimate that creates "heartburn" for both engineers and managers. This is due, in part, to the problems of establishing the functional baseline. A functional baseline is the very beginning of a requirement. It includes the MC document and the engineer's design approach. These two areas are sometimes hard to establish due to the training requirements not being adequately defined, inadequate data on the system being simulated and the requirement scope increasing from the time the estimate is developed until the project is implemented.

CHAPTER IV

SYSTEM DESIGN WORK BREAKDOWN STRUCTURE

A Work Breakdown Structure (WBS) is a product-oriented family tree composed of hardware, software, services, and other work tasks which result from project engineering efforts during the development and production of a defense material item, and which completely defines the project/program. [5] A Work Breakdown Structure (WBS) displays and defines the product to be developed or produced and relates the elements of work to be accomplished to each other and to the end product.

The Work Breakdown Structure (WBS) is primarily a cost estimating format and provides an effective and comprehensive approach that can closely correlate the flight trainer (hardware, software, service, etc.) and cost. It is so structured that it can be used to support mini-design approaches and mini-project master plans.

The Work Breakdown Structure (WBS) is developed downward from the prime objective, the trainer system which is level one, to successfully lower levels until manageable units for planning and control are derived. The Work

Breakdown Structure (WBS) element is a discrete portion of a Work Breakdown Structure (WBS). It may be either an identifiable product, set of data or a service.

By this process the subsystems and components which comprise the total system may be identified. In the initial stages of development the availability of information may limit the structure to only the second or third levels. As the design becomes better defined the structure may be expanded to the fourth, fifth or even sixth level. In general, high cost or high risk device programs should be expanded to lower levels than other work tasks.

Figure 5 represents the system design Work Breakdown Structure (WBS) for an Operational Flight Trainer (OFT) with motion and visual systems. The system design level of the Work Breakdown Structure (WBS) represents the "heart" of training system cost estimation.

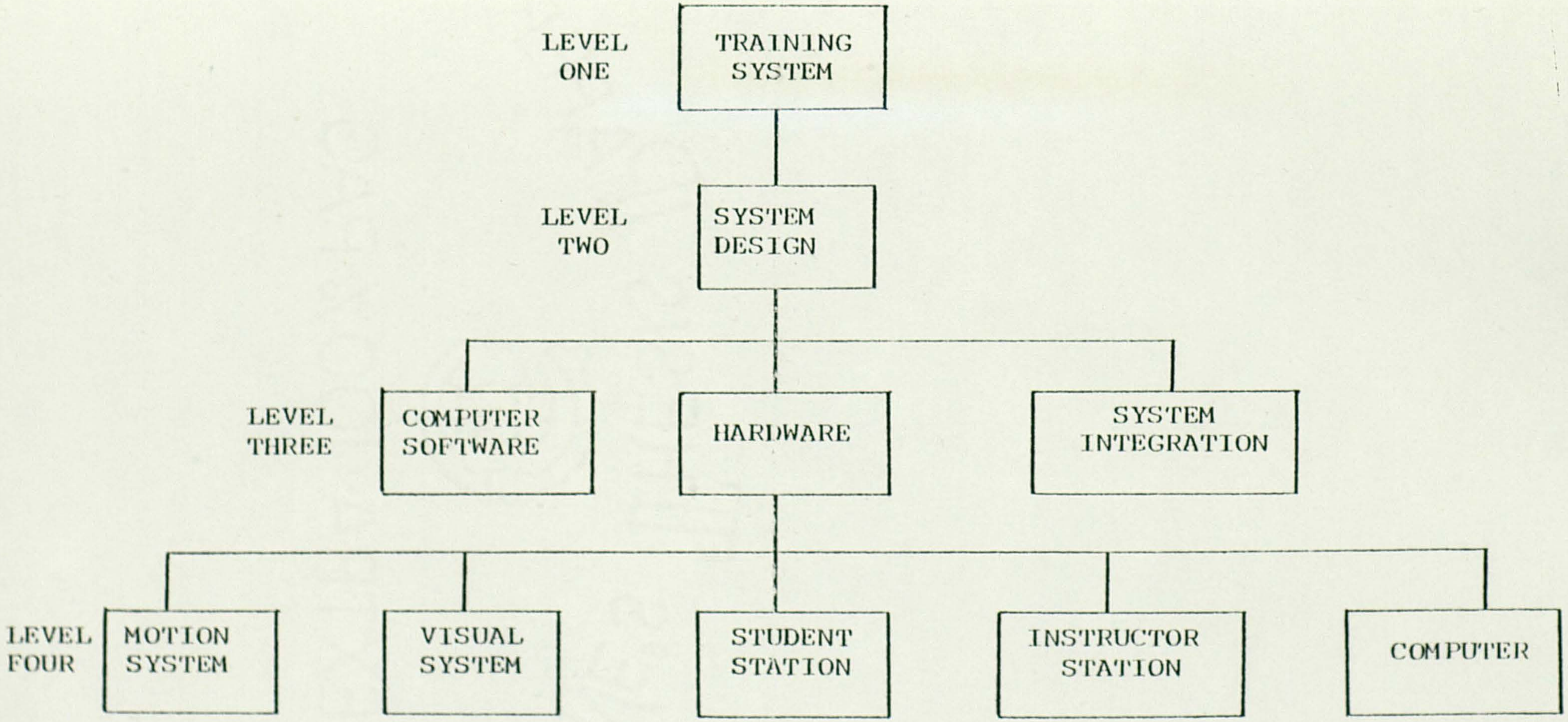


Fig. 5. Work Breakdown Structure For Operational Flight Trainer

CHAPTER V

COST ESTIMATING TECHNIQUE APPLIED TO THE MAJOR ELEMENTS OF THE SYSTEM DESIGN

The Work Breakdown Structure (WBS) elements and levels which have been identified in Chapter IV will now be examined as to what cost estimating techniques were applied.

The Trainee Station

Beginning with the trainee station, it was thought that the number of instruments specified would be a good indicator of cost. Unfortunately, the exact number of instruments is not always given in the contract performance specification.

An example of a performance specification language would be that "Instruments and controls used in the flight and ground situation, which the trainer is intended to simulate, shall be synthetically activated to meet specified performance requirements, and designed in accordance with MIL-I-82356.[6] Also of interest is that the number of instruments proposed for the same training device differ considerably.

Example: For one flight simulator contractor A proposed 39 instruments, contractor B proposed 24 instruments and contractor C proposed 44 instruments.

However, upon examining eight different contractor proposals a cost estimating relationship was established on the number of trainee stations and material cost. The data are given in Table 1. All cost estimates are normalized to the fiscal year 1976 as a base year.

TABLE 1

COST ESTIMATING RELATIONSHIP TRAINEE STATION

Contractor	Number Of Trainee Stations	Material Cost Normalized To Fiscal Year 1976
	x_i	y_i
A	2	$115,346
B	2	$167,742
C	4	$428,491
D	1	$130,855
E	1	$155,957
F	1	$188,551
G	1	$ 56,092
H	2	$299,597

The linear regression equation of y on x is:

$$y_c = a + bx \qquad \text{(Equation 1)}$$

Using the data from Table 2 and the slope equation shown below, the following computation can be made:

$$b = [n \Sigma y x - \Sigma y \Sigma x] / [n \Sigma x^2 - (\Sigma X)^2] \quad \text{(Equation 2)}$$

For the data in Table 2 the slope can be computed as:

$$b = 94824.63$$

Also, the intercept can be computed as:

$$a = \bar{y} - b\bar{x} \quad \text{(Equation 3)}$$

$$a = 26885.76$$

The regression equation for trainee station material cost then becomes:

$$y_c = 26885.76 + 94824.63\ x \quad \text{(Equation 4)}$$

The author recognizes that the intercept of the trainee station sample regression equation does not go through the origin. This is due to the high correlation coefficient percentage of equation 4 and the assumption that the number of trainee stations will be from one to four. The correlation coefficient can be determined for the following expression:

$$\hat{\rho} = \frac{n \Sigma xy = (\Sigma x)(\Sigma y)}{[n \Sigma x^2 - (\Sigma x)^2]^{\frac{1}{2}} [n \Sigma y^2 - (\Sigma y)^2]^{\frac{1}{2}}} \quad \text{(Equation 5)}$$

Using Table 2 data and equation 5, the linear correlation coefficient is computed as

$$\hat{\rho} = r = .83$$

TABLE 2

SUMS REQUIRED FOR REGRESSION COMPUTATION OF STUDENT STATION

x	y	xy	x^2	y^2	(x+y)	$(x+y)^2$
2	115,346	230,692	4	1.330469972E10	115,348	1.33051611E10
2	167,742	335,484	4	2.813737856E10	167,744	2,813804954E10
4	428,491	1,713,964	16	1.836045371E11	428,495	1.83607965E11
1	130,855	130,855	1	1.712303103E10	130,856	1.72329274E10
1	155,957	155,957	1	2.432258585E10	155,958	2.432289776E10
1	188,551	188,551	1	3.55514796E10	188,552	3.55518567E10
1	56,092	56,092	1	3.146312464E9	56,093	3.146424649E9
2	299,597	599,194	4	8.975836241E10	299,599	8.97595608E10
14	1,542,631	3,410,789	32	3.949483867E11	1,542,645	3.949552083E11

n = 8 pairs of observations, Σxy = 3,410,789, Σy^2 = 3.949483867E11

Σx = 14 , Σx^2 = 32 , $\bar{x}$ = 1.75

Σy = 1,542,631 , $\bar{y}$ = 192828.875

A hypothesis test was performed to determine if there was a correlation in the bivariate population. Since the sample size n is less than 30, the "t" statistic used to test the null hypothesis that there is no correlation is as follows:

$$t = r \left[n-2)/(1-r^2)\right]^{\frac{1}{2}} \qquad \text{(Equation 6)}$$

which is distributed as t_{n-2} if the null hypothesis is true.

Applying the test to the above data with α equal 0.05, the null hypothesis H_o : r = 0 would be accepted if $-2.447 < t_6 < 2.447$. The value of r obtained is

$$t = 0.83 \left[(8-2)/(1-.6889)\right]^{\frac{1}{2}} = 3.645.$$

Since 3.645 is larger than 2.447 the null hypothesis is rejected and the alternate hypothesis is accepted. The value of r is not the result of chance variation. It is significant.

The variance and the standard deviation of the regression is next estimated to determine how good the regression cost estimating model is as a predictive device. The estimate of the variance is:

$$(\sigma_{yx})^2 = \frac{\Sigma\,(y-y_c)^2}{n-2} \qquad \text{(Equation 7)}$$

Using the computed data from Table 3

$$(\sigma_{yx})^2 = 500779221.3$$

$$\sigma_{yx} = 22378.09691$$

To determine the sampling error in the estimated slope b the unbiased estimation of the variance b must be determined by the equation:

$$\sigma_b^{\ 2} = \frac{\sigma_{yx}^{\ 2}}{\Sigma x^2 - [(\Sigma x)^2/n]} \qquad \text{(Equation 8)}$$

Again, using data from Table 2 and $\sigma_{yx}^{\ 2}$

$$\sigma_b^{\ 2} = 66,770,562.84$$

$$\sigma_b = 8,171.32$$

If the population slope B is zero then the sample regression equation is of no value as a predictive device.

To find the 95 percent confidence interval for the population slope B , formulate the null hypothesis that the slope is zero. The test is to be performed with α equal to 0.05.

$$H_o : B = 0$$

$$H_1 : B \neq 0$$

TABLE 3

COMPUTATION OF THE ESTIMATE OF STANDARD DEVIATION OF REGRESSION

Observed Values		Computed		
Trainee Stations	Material Cost	Material Cost		
x	y	y_c	$y-y_c$	$(y-y_c)^2$
2	115,346	216,535.0333	-101,189.0333	1.023922046E10
2	167,742	216,535.0333	- 48,793.0333	2380760099
4	428,491	406,184.3	22,306.7	49758864.9
1	130,855	121,710.4	9,144.6	83623709.16
1	155,957	121,710.4	34,246.6	1172829612
1	188,551	121,710.4	66,840.6	4467665808
1	56,092	121,710.4	- 65,618.4	4305774419
2	299,597	216,535.0333	83,061.9067	6899290312
14	1,542,631	1,542,631	.0001	3.004675328E10

For a small sample, less than 30, the student t test is used.

$$t = \frac{b - B}{\sigma_b} \qquad \text{(Equation 9)}$$

At the 95 percent level of confidence the critical value for the student t test with n-2 degrees of freedom is $\pm$ 2.447. From previous computed data

$$t = \frac{94824.63 - 0}{8171.32} = 11.60$$

which is greater than 2.447. Thus, it is concluded that the difference between the estimated slope and a hypothetical population slope cannot be explained by chance variation alone, and the null hypothesis is rejected at the 5 percent level of significance. The conclusion suggests that H_1 is true and that the sample regression equation should not be discarded. It can be used for predictive purposes.

The 95 percent confidence interval for B, the hypothetical population slope is

$$b \pm 2.447\ (\sigma_b) \qquad \text{or}$$

$$74829.39 < B < 114819.87$$

It was decided that the sample linear regression equation could be used to predict the mean of y on x, (μ_{yx}) for a new observation of y, (y), given the value of x. To develop the confidence interval for μ_{yx} the unbiased estimate of the variance of y_c must be computed from the following equation:

$$\sigma_{y_c}{}^2 = (\sigma_{yx})^2 \left[1/n + \left[(x-\bar{x})^2/\Sigma\,(x_i - \bar{x})^2\right]\right] \quad \text{(Equation 10)}$$

Each given value of x must be computed separately from previous data to form Table 4. For x to equal one student station, the computation would be

$$\sigma_{y_c} = 10007.7891$$

Then when x equals one; i.e., the cost for one trainee station, is to be computed the prediction equation would be

$$y_c = 26885.76667 + 94824.6333(1) = 121710.4 \text{ or}$$

121710, and finally,

$$y_c \pm t_{n-2;\alpha/2}\sigma_{y_c} = 121710 \pm 2.447\ (10007.7891)$$

$$97221 < \mu_{yx} < 146199$$

Table 4 is the computation of 95 percent confidence interval for true regression line for trainee stations material cost. It gives the estimated material cost for one, two, three, and four trainee stations.

A graphic display of material cost versus number of trainee stations is shown in Figure 6.

Additional cost data with remarks are shown in Table 5.

The average manufacturing labor and engineering hours were computed on an extremely small sample size to develop a 95 percent and 80 percent confidence interval for the population mean. Letting s equal the sample standard deviation, n the sample size, $\bar{x}$ the sample mean, α the type 1 error probability, and $1 - \alpha$ the confidence interval, the following statistics may be used:

$$s = \left[\left[\sum_{i=1}^{n} (x_i - \bar{x})^2 \right] / (n - 1) \right]^{\frac{1}{2}} \quad \text{(Equation 11)}$$

Using the student's t-distribution for sample size less than 30 when the population variance is unknown, the confidence interval for μ would be:

$$\bar{x} \pm t_{n-1;\alpha/2} \quad (s/\sqrt{n})$$

From Table 5 the following manufacturing labor data were computed

$$\bar{x} = 4{,}310.2$$

$$s = 2{,}532$$

$$n = 5$$

$t_{4;0.025} = 2.776$

$s/\sqrt{n} = 1,132.1565$

$\bar{x} \pm (2.776)(1,132.1565)$

$1,167 < \mu < 7,453$

The 95 percent confidence interval for the manufacturing labor manhours population mean μ would be somewhere between 1,167 and 7,453 per training station. From Table 5 the following engineering manhour data were computed:

$\bar{x} = 13,674$

$s = 8,121.8$

$n = 3$

$t_{2;.10} = 1.886$

$s/\sqrt{n} = 4,689$

$\bar{x} \pm (1.886)(4,689)$

$4,830 < \mu < 22,517$

The 80 percent confidence interval for the engineering labor manhours population mean μ would lie somewhere between 4,830 and 22,517. Since the sample size is small and dispersion of the data is so great, only an 80 percent confidence interval could be realized.

TABLE 4

COMPUTATION OF 95 PERCENT CONFIDENCE INTERVAL FOR TRUE REGRESSION LINE FOR TRAINEE STATIONS MATERIAL COST

x	$x - \bar{x}$	$(x-\bar{x})^2$	σ_{y_c}	y_c	$y_c \pm 2.447\ (\sigma_{y_c})$
1	- .75	.5625	10,007.789	121,710	97,221---146,199
2	.25	.0625	8,171.325	216,535	196,540---236,530
3	1.25	1.5625	12,920.000	311,359	298,439---342,974
4	2.25	5,0625	20,015.578	406,184	357,206---455,162

x is the number of trainee stations

σ_{y_c} is the standard error of y_c

y_c is the material cost estimate of the trainee station(s)

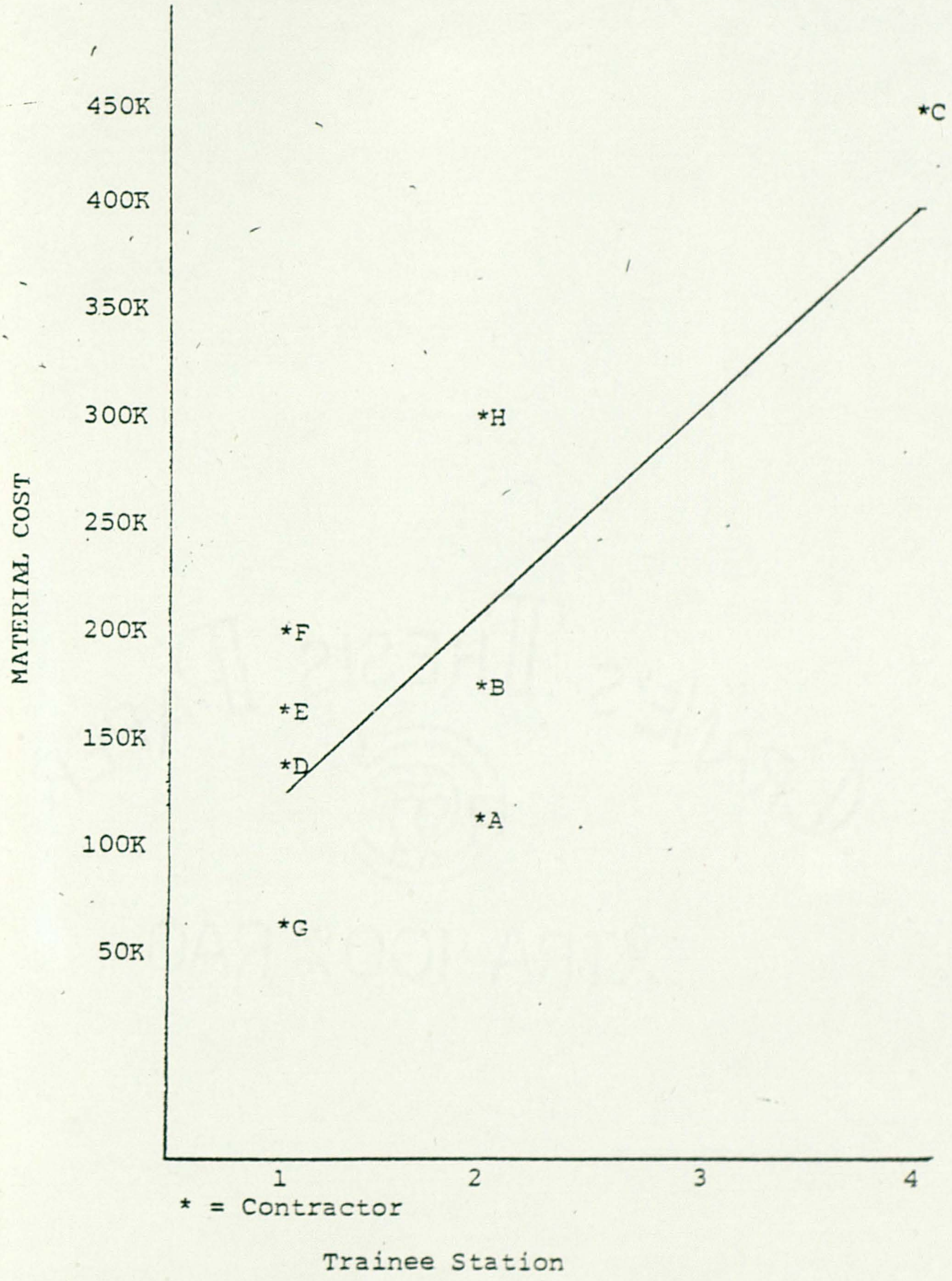


Fig. 6. Material Cost vs. Trainee Station

TABLE 5

TRAINEE STATION

Contractor	Device	Fiscal Year 1976 Material Cost	Remarks
A	Weapon System Trainer	$115,346	Two Trainee Stations (One Trainee Station Gunner, One Trainee Station Pilot)
B	Operational Flight Trainer	$167,742	Two Trainee Stations (Each has Pilot and Copilot) Total Cost Material, Engineering and Labor: $442,330
C	Operational Flight Trainer	$428,491	Four Trainee Stations (Each has Pilot and Copilot)
D	Operational Flight Trainer	$130,855	One Trainee Station (Pilot and Copilot) Engineering Manhour Estimate: 11,199 Labor Manhour Estimate: 6,847
E	Operational Flight Trainer	$155,957	One Trainee Station (Pilot and Copilot) Engineering Manhour Estimate: 22,745 Labor Manhour Estimate: 6,684
F	Operational Flight Trainer	$188,551	One Trainee Station (Pilot and Copilot) Engineering Manhour Estimate: 7,077 Labor Manhour Estimate: 3,774
G	Operational Flight Trainer	$299,597	One Trainee Station (Pilot and Copilot) Material Cost: $109,193 Labor Manhour Estimate: 3,485 One Trainee Station Sensor; 22 Instruments Material Cost: $190,404 Labor Manhour Estimate: 761

The Instructor Station

Using data from seven different contractor proposals, the following cost estimating relationship was established on the trainee station material cost and the instructor station material cost. The data are given in Table 6. All cost data have been normalized to the fiscal year 1976 for a base year. Using Equation 1 and data from Table 7 , the regression model for instructor station material cost becomes:

$$y_c = -21464.42819 + .4961663989\ x \quad \text{(Equation 12)}$$

The linear correlation using equation 5 and the same data become $\hat{\rho} = r = .9468$

To test for correlation in the bivariate population using the same statistical method for instructor station that was used in testing trainee station with α equal 0.05, the null hypothesis $H_o: r = 0$ would be accepted if $-2.571 < t_5 < 2.571$. The value of r is obtained using equation 6 and is

$$t = .9468\ [(7-2)/(1-.89643)]^{\frac{1}{2}}$$

$$t = 6.57849$$

At the 95 percent confidence interval the null hypothesis (H_o) is rejected. The value of r is not the result of chance variation and is significant.

TABLE 6

COST ESTIMATING RELATIONSHIP INSTRUCTOR DISPLAY SYSTEM (NORMALIZED TO FISCAL YEAR 1976)

Contractor	Material Cost of Student Station	Material Cost of Instructor Station
A	$115,346	$ 21,108
B	$428,491	$196,072
C	$167,742	$103,003
D	$130,855	$ 42,748
E	$155,957	$ 30,776
F	$ 56,092	$ 13,063
G	$299,597	$114,828

The standard deviation of this regression model is computed next to determine if it is a good predictive tool.

Using equation 7 and the data in Table 7 the following computations are made

$$\sigma_{yx}^2 = 553{,}998{,}642.2$$

$$\sigma_{yx} = 23{,}537.17$$

Again, to determine the sampling error in the estimated slope b of the regression model, the unbiased estimator

TABLE 7

COMPUTATION OF THE ESTIMATED STANDARD DEVIATION
INSTRUCTOR STATION REGRESSION MODEL

Observed Values			
Student Station Material Cost	Instructor Station Material Cost	Calculated Instructor Station Material Cost	
x	y	y_c	$(y-y_c)^2$
115,346	21,108	35,766.38126	214,868,141.2
428,491	196,072	191,138.4082	24,340,327.64
167,742	103,003	61,763.51589	1,700,695,050.
130,855	42,748	43,461.42594	508,976.5692
155,957	30,776	55,916.19488	632,029,398.6
56,092	13,063	6,366.537457	44,842,610.59
299,597	114,828	127,185.5364	152,708,706.4
1,354,080	521,598	521,598.0000	2,769,993,211.

of the variance b must be determined by equation 8. Using data from Table 7 and the standard deviation (σ_{yx}) of this regression model the following results were obtained

$$\sigma_b^2 = .0056841552$$

$$\sigma_b = .0753933369$$

The following is the test on the population slope B at the 95 percent confidence interval. Let α equal 0.05 and formulate the null hypothesis that the population slope B is zero. The alternate hypothesis is that B does not equal zero.

Since this is a small sample of seven observations, the student t distribution is used. At the 95 percent confidence interval the critical value with five degrees of freedom is 2.571.

$$t = \frac{b-B}{\sigma_b} = 6.581$$

The result is two and one-half times the critical value for the 95 percent confidence interval. The difference between the estimated slope and a hypothetical population slope cannot be explained by chance variation, and the null hypothesis is rejected at the five percent level of significance. It could even be rejected at the one percent level of significance since the critical value for 99 percent confidence interval is 4.032. This conclusion suggests that H_1, the alternate hypothesis, is true; and that this sample regression equation should not be discarded, but used as a predictive aid in determining the material cost of instructor stations. The 95 percent confidence interval for B is

$$b \pm 2.571\ \sigma_b \qquad \text{or}$$

$$.30 < B < .69$$

Table 8 was computed using the unbiased estimate of the variance of y_c to show the 95 percent confidence interval of prediction for material cost of instructor station. The computation for equation 10 is

$$\sigma_{y_c}^{\ 2} = 55399642.2 \left[\frac{1}{7} + \frac{(x-\bar{x})^2}{9.746367191E10} \right]$$

A graphic display of instructor station(s) material cost versus trainee station material cost is shown in Figure 7. Additional cost data with remarks are shown in Table 9.

The average manufacturing labor and engineering hours were computed using the same statistical method

TABLE 8

COMPUTATION OF 95 PERCENT CONFIDENCE INTERVAL FOR TRUE REGRESSION LINE FOR INSTRUCTOR STATION MATERIAL COST

Number Of Student Stations	Estimated Student Station Material Cost			Estimated Instructor Station Material Cost	
	x	$x-\bar{x}$	σ_{y_c}	y_c	$y_c \pm 2.571 (\sigma_{y_c})$
1	121,710	- 71,730	10,411	38,924	12,157 - 65,691
2	216,535	23,095	9,065	85,973	62,667 - 109,279
3	311,359	117,919	12,577	133,021	100,685 - 165,356
4	406,184	212,744	18,341	180,070	132,915 - 227,225

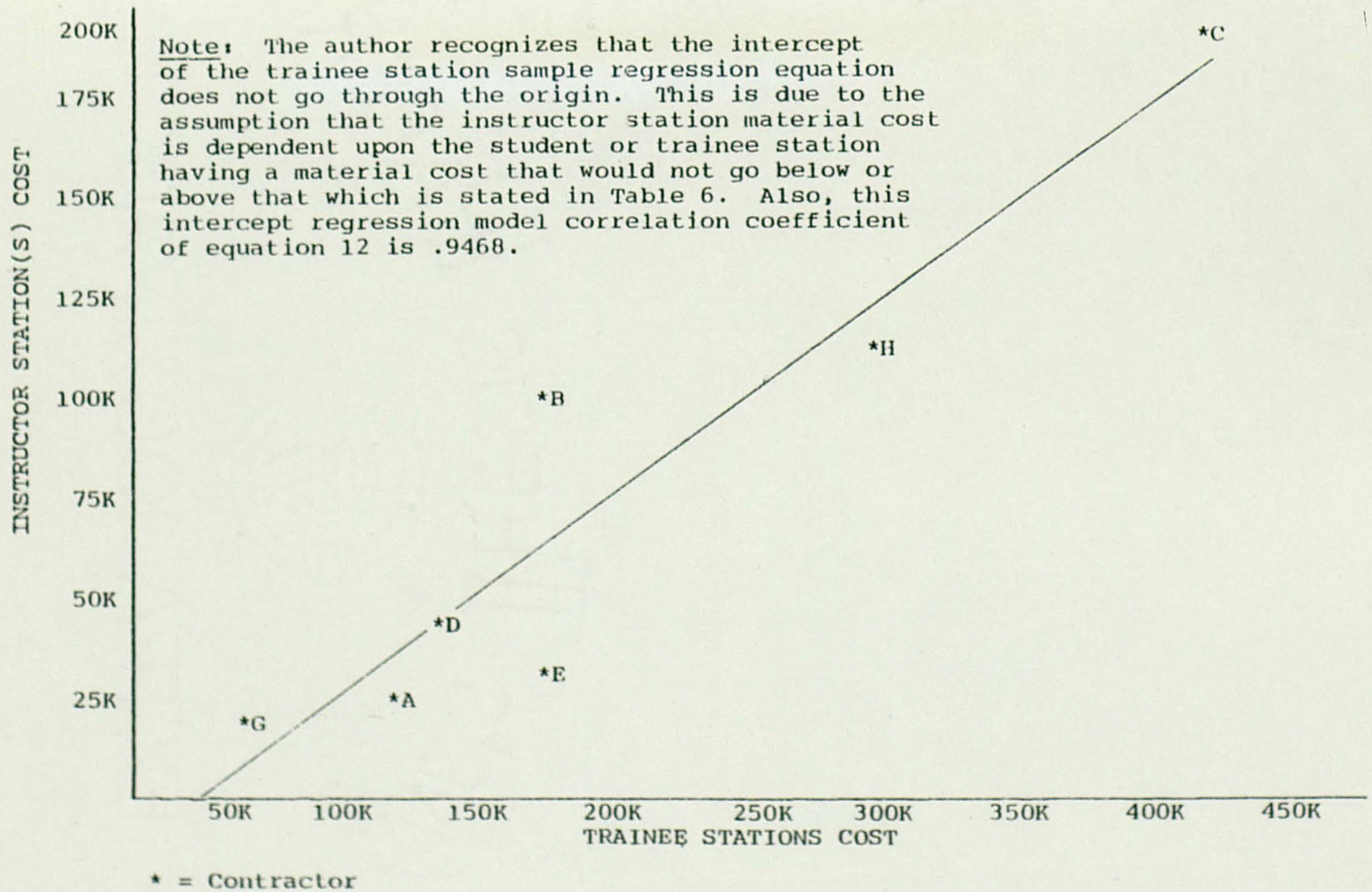


Fig. 7. Instructor Station Material Cost vs. Trainee Station Material Cost

TABLE 9

INSTRUCTOR STATION

Contractor	Device	Fiscal Year 1976 Material Cost	Remarks
A	Weapon System Trainer	$ 21,108	Console, panel assembly, keyboard, card gate assembly, headset. One instructor station pilot, one instructor station gunner.
B	Operational Flight Trainer	$103,003	Remarks similar to Contractor A. Two instructor stations.
C	Operational Flight Trainer	$196,072	Number of CRT's (6), number of display generators, mini or micro computer required for the system, color or monochrome software for the system, number of consoles, number of refresh memories, record and playback capabilities, keyboard. One instructor station.
D	Operational Flight Trainer	$ 42,748	CRT, display processor, function generator, character generator, refresh memory, keyboard, frame.
E	Operational Flight Trainer	$ 30,776	CRT, refresh memory, character generator, micro processor, display controller, vector position circle generator, keyboard, frame. Engineering Manhour Estimate: 4,222 Manufacturing Labor Manhour Estimate: 1,438

TABLE 9 - Continued

Contractor	Device	Fiscal Year 1976 Material Cost	Remarks
G	Operational Flight Trainer	$ 13,063	One instructor station. Parameters similar to Contractor C.
H	Weapon System Trainer	$114,828	Three instructor stations. Operational Flight Trainer instructor station CRT keyboard.

for the trainee station. This time 90 percent and 95 percent confidence intervals were computed on the population mean μ for the manufacturing labor and the engineering manhours. Since the sample sizes were less than 30 the student's t distribution was used. The manufacturing labor manhours were computed as

$$\bar{x} = 1329.34$$

$$s = 426.51$$

$$n = 3$$

$$s/\sqrt{n} = 246.25$$

$$\bar{x} \pm t_{.975;2}\ (s/\sqrt{n}) \quad \text{or}$$

$$\bar{x} \pm 4.303\ (246.25)$$

$$269 < \mu < 2389$$

The 95 percent confidence interval for manufacturing labor manhours population mean μ would be between 269 and 2389 for cost estimating purposes.

The engineering manhours were computed as

$$\bar{x} = 1907$$

$$s = 1791.77$$

$$n = 5$$

$$s/\sqrt{n} = 801.3$$

$$\bar{x} \pm t_{.950;4}\ (s/\sqrt{n}) \quad \text{or}$$

$$\bar{x} \pm 2.132\ (801.3)$$

$$198 < \mu < 3616$$

The 90 percent confidence interval for engineering manhours population mean μ would be between 198 and 3616.

The Motion System

Motion systems are used with Operational Flight Trainers to add propriceptor cues to students when performing certain training maneuvers. Some of the propriceptor cues that a motion system adds to an Operational Flight Trainer are skids, slips, banks, turns, climbs, dives, accelerations, transitions, vibrations, and aircraft touchdowns. There are other characteristics, depending upon the specific aircraft for which the Operational Flight Trainer is being designed. The motion system is illustrated in Figure 8. Using data from eleven different Operational Flight Trainers and four different sources, a cost estimating relationship was established on the motion system total cost and certain characteristics of the motion system. The stepwise linear regression model from the BMD[7] package was employed to determine this relationship. The first computer run used dummy variables identifying the contractors. By using the dummy variable,

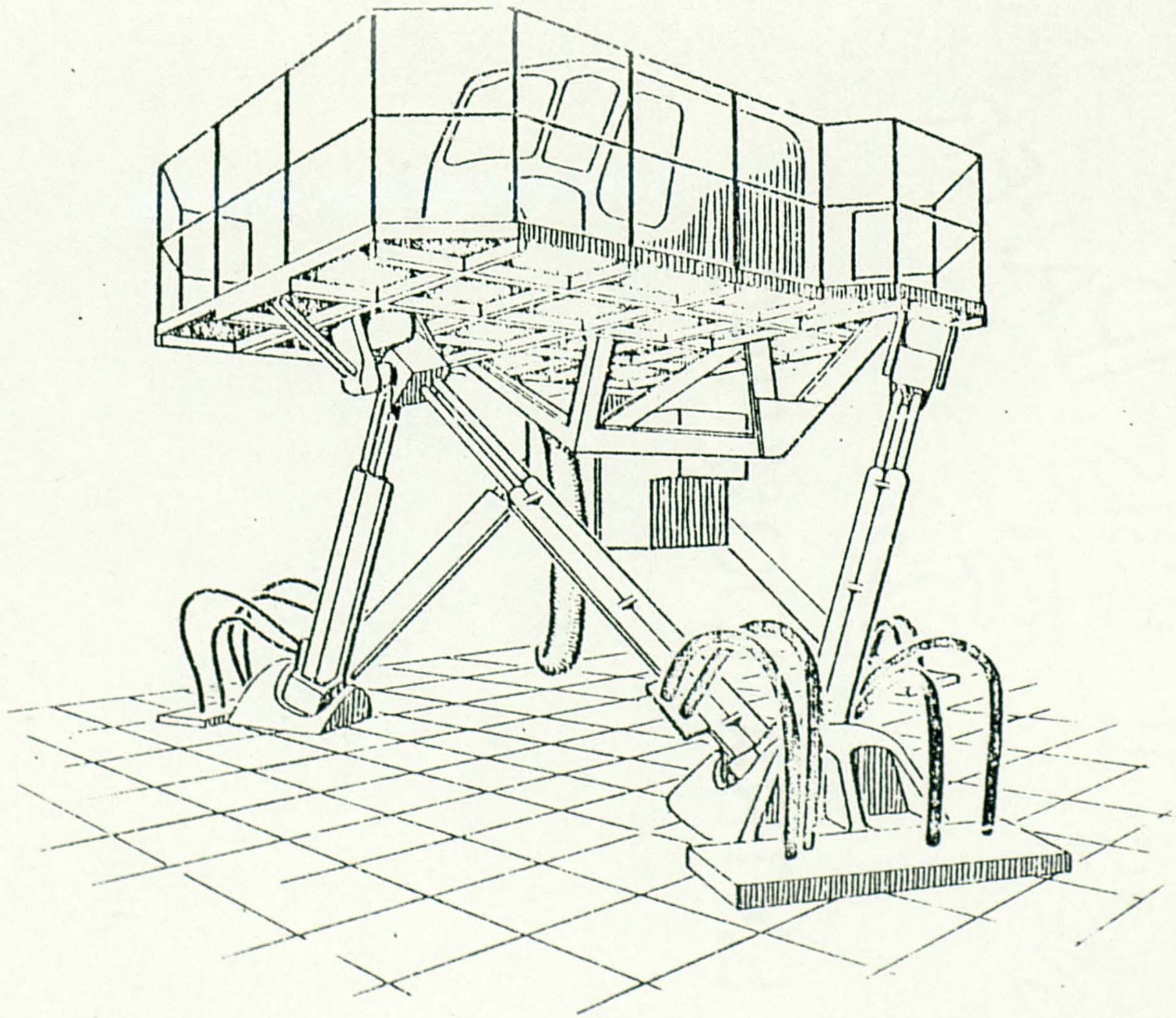


Fig. 8. Motion System

differences inherent in a particular company were masked out (i.e., the difference in labor rates or the difference in raw material cost, etc.). The linear correlation of this run was 99 percent.

The computer data runs are listed in Appendix A. The equation for the cost of motion systems using the dummy variables are:

$$y_c = 693.56 - 153.82(DEGFRE) + 1.00(TOTWT) - 2.59(YAW) + 1.92(VERTCL) + 3.99(LATRAL) + 2.61(LONG) + \text{Contractor Data} \quad \text{(Equation 13)}$$

Contractor data are

Contractor	Data
I	- 19.70
J	- 72.22
K	95.89
L	00.00

All cost data are in thousands of dollars and normalized to fiscal year 1976 base year.

Table 10 describes variables and the data range that can be used in this cost estimating relationship (CER) model for motion systems.

TABLE 10

DATA FOR MOTION SYSTEM CER MODEL

Variable	Definition	Data Range
DEGFRE	Degrees of Freedom*	3 to 6
TOTWT	Total Weight in Thousands of Pounds	12K to 47K
VERTCL	Vertical Excursion in Inches	0" to 96"
PITCH	Pitch Excursion in Degrees	30^{o} to 58^{o}
YAW	Yaw Excursion in Degrees	18^{o} to 66^{o}
LATRAL	Lateral Excursion in Inches	0" to 96"
LONG	Longitudinal Excursion in Inches	0" to 104"

*The six degrees of freedom for a motion platform are pitch, roll, yaw, vertical, lateral, and longitudinal.

The standard error of the estimate of this CER model is 5.38.

A second cost estimating relationship model was developed not using the dummy variables. The linear correlation on this model is .9482. This computer data run is also listed in Appendix A. The equation for this cost estimating relationship model is:

$$y_c = -103.70 + 9.01(\text{TOTWT}) + 3.25(\text{PITCH}) + .56(\text{VERTCL}) \qquad \text{(Equation 14)}$$

From Table 10, the total weight, pitch and vertical excursions can be employed to calculate the range for cost estimating. It is interesting to note that total weight, pitch and vertical excursions affect the price of motion system platforms. This particular CER model has an advantage over the first in that the cost estimator would not have prior knowledge as to which contractor would be bidding. The first CER model has the advantage of evaluating a contractor's cost proposal when contractors are known.

Computer Hardware System

For the computer hardware the following approach and assumptions were made. The baseline system would consist of one CPU with memory and all peripherals in the small (midi) size computer range to support a one trainee station without visual, motion and radio navigation. This Operational Flight Trainer (OFT) would be a low performance trainer. If visual is required, only one trainee station and one instructor station would be configured for a fixed wing Operational Flight Trainer (OFT). A second CPU would be required to interface and service the visual system. The cost of the second CPU with memory and peripherals is provided for in the flow diagram depicted in Figure 9. Without visual, one CPU can service up to two trainee stations. If there are three or four trainee stations another CPU of the same type would be required with memory and peripherals. Figure 9, Flow Diagram for Determining Total Cost of Computer(s) Hardware, is used to determine the total computer hardware cost beginning with the baseline cost of $100,000. All computer hardware data includes engineering, manufacturing labor, material, overhead, general, and administrative costs. Computer hardware data were examined on the basis of low cost (LC), high cost (HC) and most likely cost (MLC) for each decision factor within the computer hardware flow diagram.[8] Expected cost (EC) was computed from the equation:

$$EC = \frac{LC + 4(MLC) + HC}{6} \qquad \text{(Equation 15)}$$

The variance (σ^2) would be computed from the equation as:

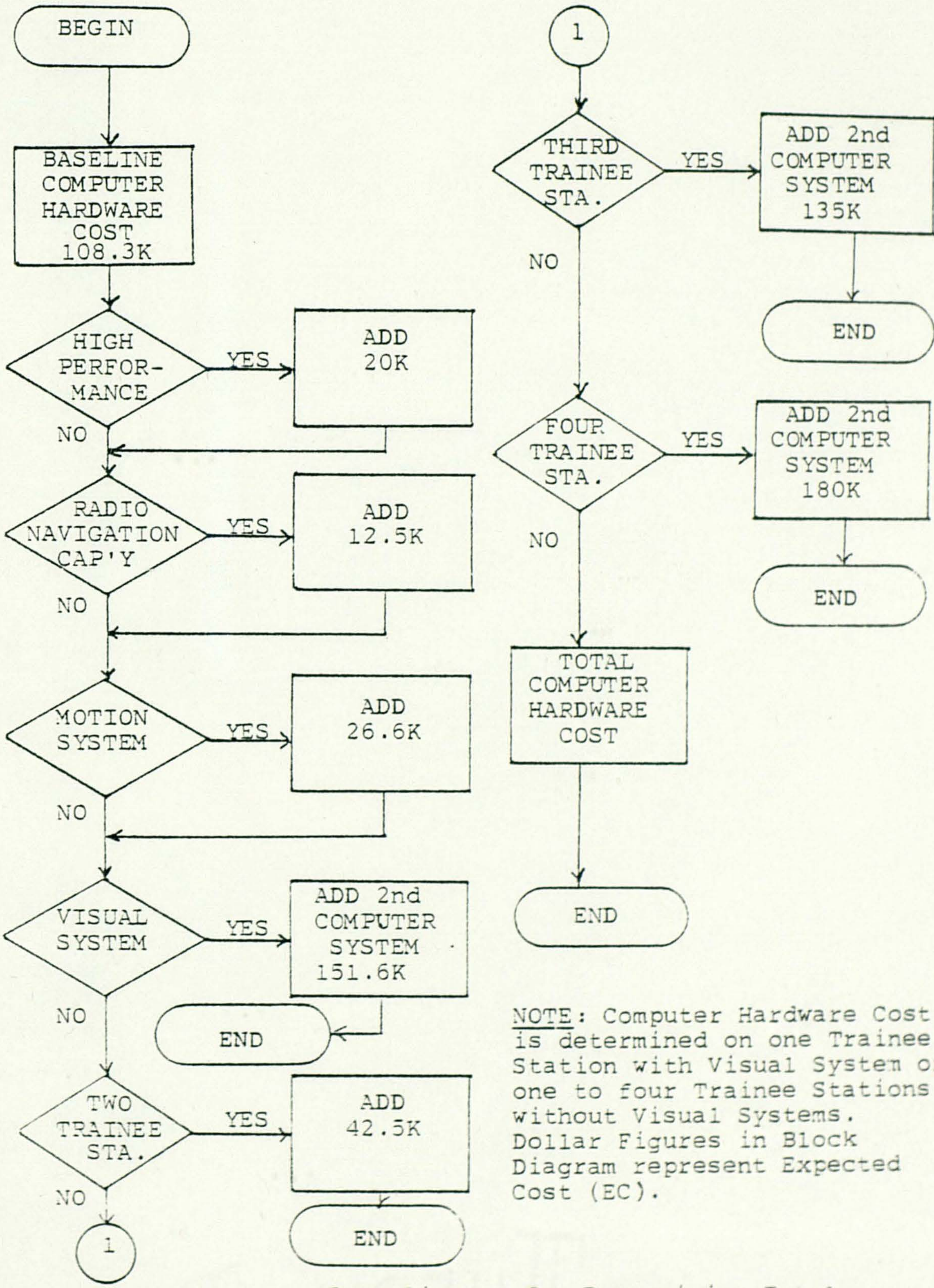
$$\sigma^2 = \left(\frac{LC - HC}{6}\right)^2 \qquad \text{(Equation 16)}$$

Table 11 gives the complete listing of the computer hardware decision factors, variances and cost data.

TABLE 11

COMPUTER HARDWARE COST DATA

Factors	Expected Cost (EC)	Variance (σ^2)	Low Cost (LC)	Most Likely Cost (MLC)	High Cost (HC)
Base Line Computer Hardware Cost	108.3K	69.4K	100K	100K	150K
High Performance	20K	11.1K	10K	20K	30K
Radio Navigation Capability	12.5K	.694K	10K	12.5K	15K
Motion System	26.6K	11.1K	20K	25K	40K
Visual System	151.6K	625K	100K	140K	250K
Two Trainee Stations	42.5K	56.25K	25K	40K	70K
Three Trainee Stations	135K	136.1K	100K	135K	170K
Four Trainee Stations	180K	100K	150K	180K	210K



NOTE: Computer Hardware Cost is determined on one Trainee Station with Visual System or one to four Trainee Stations without Visual Systems. Dollar Figures in Block Diagram represent Expected Cost (EC).

Fig. 9. Flow Diagram for Determining Total Cost of Computer(s) Hardware

Visual Systems

Visual systems fall into two major categories. They are camera/modelboard and computer image generators (CIG's). Camera/modelboard visual system is one which utilizes a television camera which is "flown" over a scale model representing a portion of real-world terrain. The television scene, thus, generated is then presented to the trainee on a suitable display. The display is generally comprised of a television tube with suitable optics to create a real-world perspective.

A computer generated imagery (CGI) visual system replaces the television camera and modelboard of the camera model system with a digital environment stored in the computer as a group of surfaces comprising terrain and cultural objects. Through digital computations the environment is processed to create a scene on the trainee's display.

The flow diagram for estimating the cost of visual system is shown in Figure 10.[9] Only one trainee station and one instructor station will be used when estimating the cost of a visual system. The visual system cost includes engineering, manufacturing labor, material, overhead, general, and administrative expenses. Visual systems cost data were analyzed by the same method used in determining computer hardware data. Equations 15 and 16 were used to develop Table 12, Visual System Cost Data.

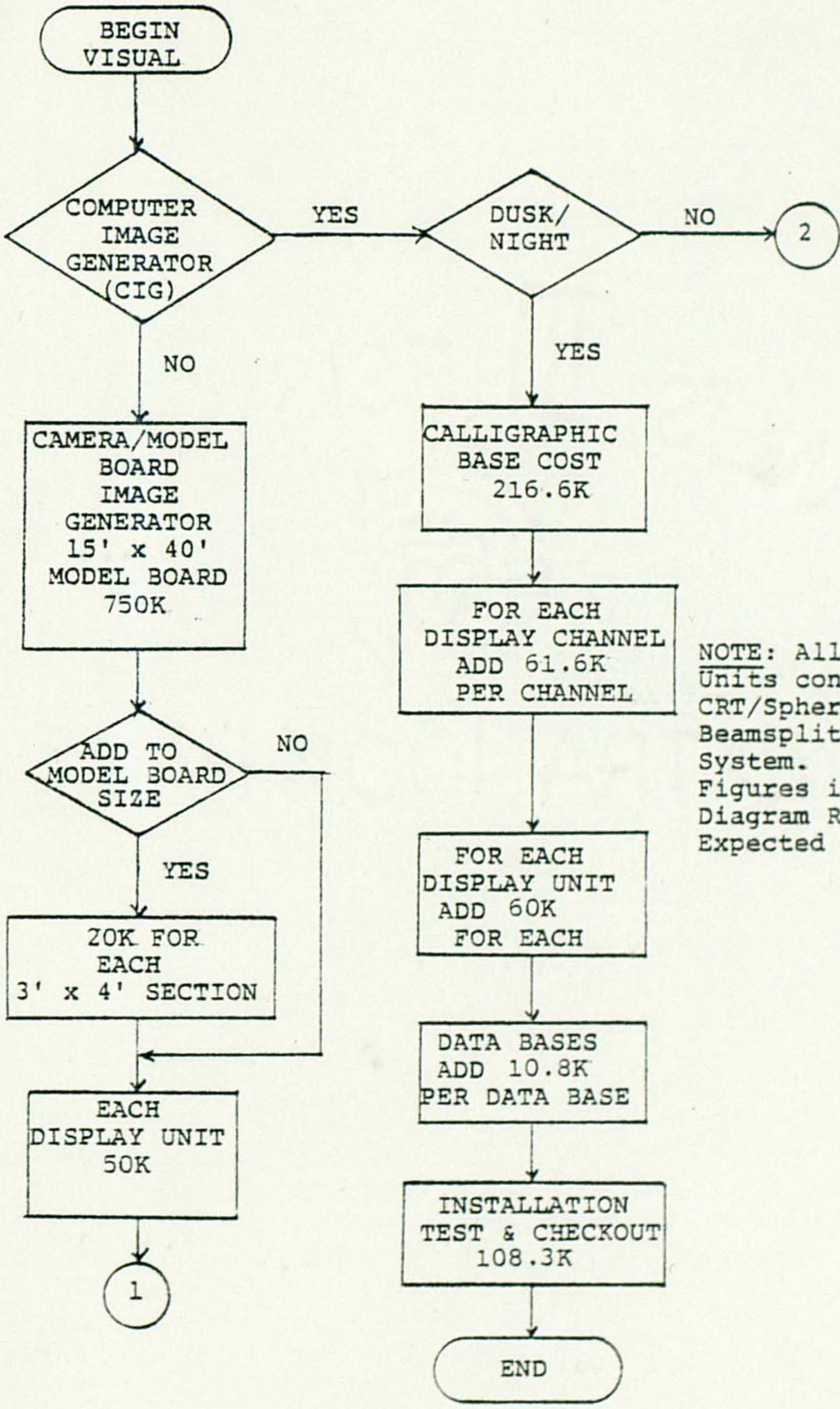
TABLE 12

VISUAL SYSTEM COST DATA

Components	Expected Cost (EC)	Variance (σ^2)	Low Cost (LC)	Most Likely Cost (MLC)	High Cost (HC)
Camera/ Modelboard Image Generator Modelboard 15' x 40'	750K	13,611K	500K	700K	1,200K
3' x 4' Section	20K	11.1K	10K	20K	30K
Display Unit	50K	11.1K	40K	50K	60K
Installation Cost	200K	1,111.1K	150K	200K	300K
Computer Image Generator (Dusk/Night) Calligraphic Base Cost	216.6K	1,111.1K	150K	200K	350K
Each Display Channel	61.6K	25K	50K	60K	80K
Each Display Unit	60K	11.1K	50K	60K	70K
Data Bases (Per Data Base)	10.8K	6.25K	5K	10K	20K
Installation Test & Checkout	108.3K	625K	50K	100K	200K

TABLE 12 - Continued

Components	Expected Cost (EC)	Variance (σ^2)	Low Cost (LC)	Most Likely Cost (MLC)	High Cost (HC)
Computer Image Generator (Day/Dusk/Night) Calligraphic Base Cost	900K	27,777.7K	600K	800K	1,600K
Each Display Channel	291.6K	625K	200K	300K	350K
Each Display Unit	60K	11.1K	50K	60K	70K
Each Data Base	53.3K	177.7K	20K	50K	100K
Installation and Checkout	250K	1,111.1K	150K	250K	350K



NOTE: All Display Units consist of CRT/Spherical Mirror/ Beamsplitter Display System. Dollar Figures in Block Diagram Represent Expected Cost.

Fig. 10. Flow Diagram for Cost Estimating on Visual System

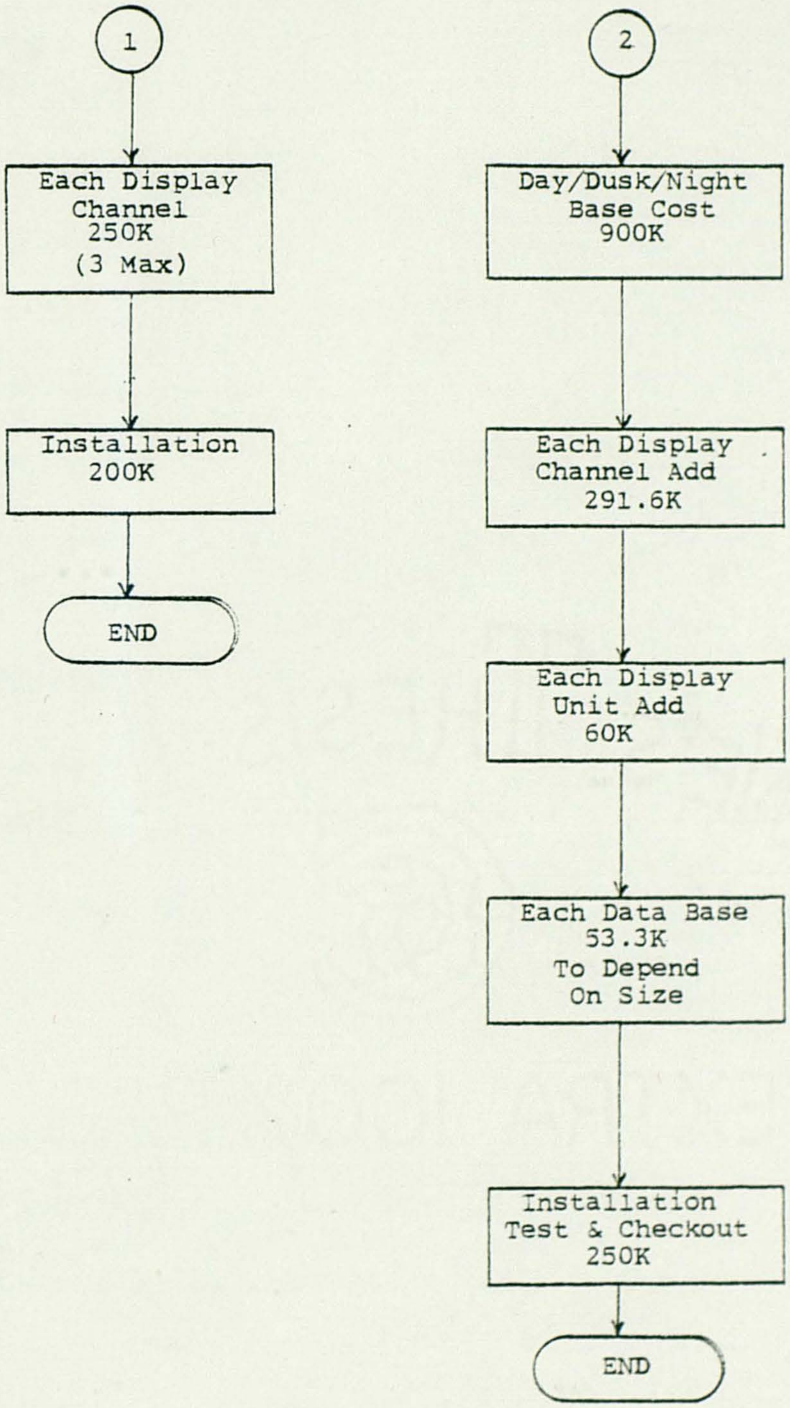


Fig. 10. Flow Diagram for Cost Estimating on Visual System (Cont.)

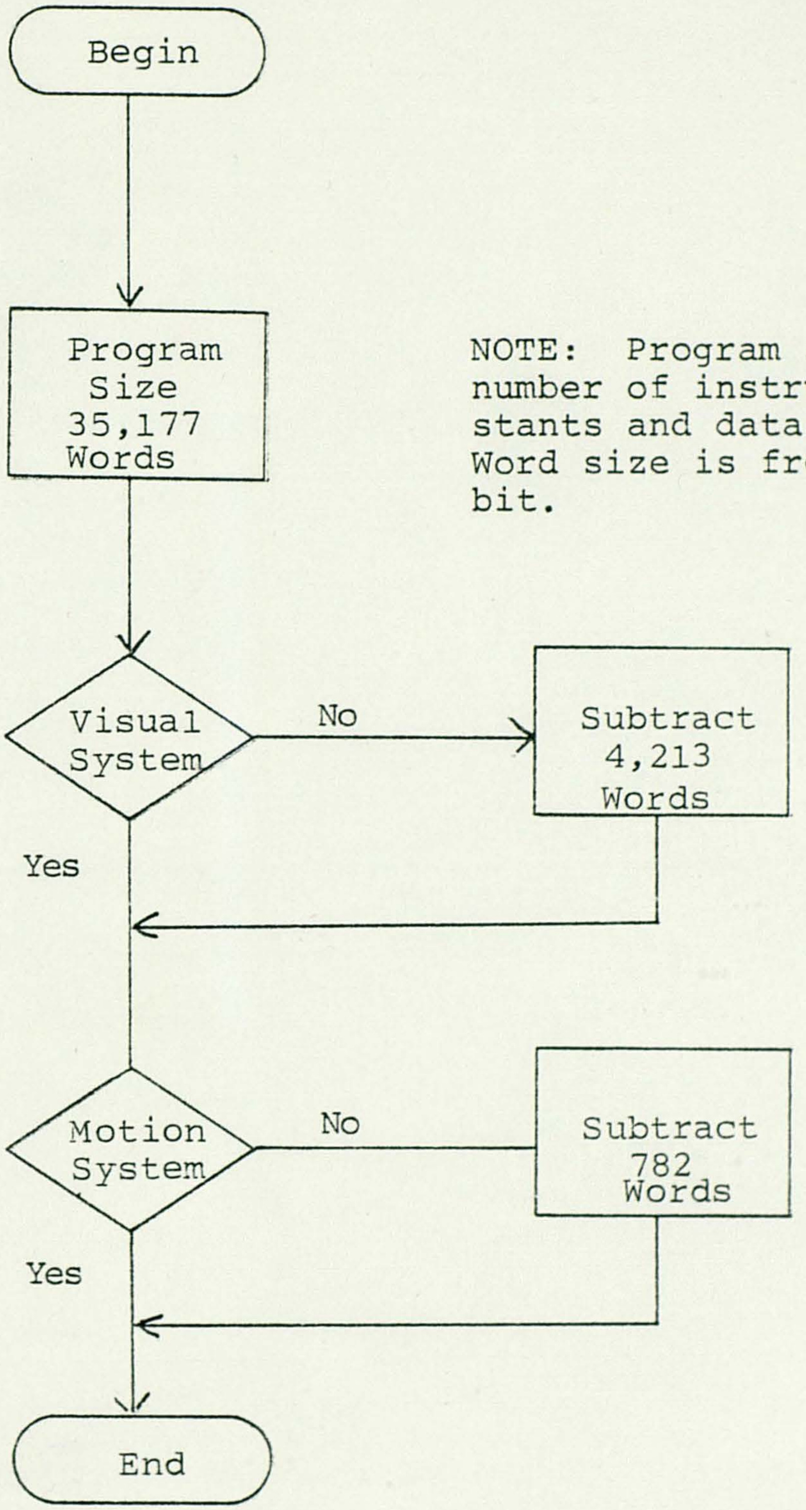
Computer Software

The function of the Operational Flight Trainer (OFT) computer program is to simulate the aircraft engines, aircraft systems, communication/navigation systems, flight control systems, media, sound, and control the motion system. The Operational Flight Trainer (OFT) computer program also interfaces with the visual system; monitors the instructor display station; solves the aero equations for that particular aircraft; monitors the performance of students; and generally controls, through the instructor station, the testing of students.

The size of the computer program must first be estimated before a cost evaluation can be determined. The program task was tallied for nine Operational Flight Trainer (OFT) computer software systems. From this data a sample mean $\mu_{\bar{x}}$ of 35,177 computer word size, and a sample standard deviation σ_s of 9,156 was computed. In the sample the minimum and maximum program sizes were 21,792 and 46,994. The 99 percent confidence interval for estimating the hypothetical population mean μ using the student t distribution was

$$24{,}938 < \mu < 45{,}417$$

The Operational Flight Trainers (OFT's) used in these data samples included a visual system and a motion system. The flow diagram in Figure 11 and the sample statistical mean shows the procedure for determining the expected computer program size for an Operational Flight Trainer (OFT). The flow diagram estimates one trainee station program size equal to 35,177. The flow diagram subtracts from the program size if the visual system is not included. The sample mean $\mu_{\bar{x}}$ for the visual system interface program was computed at 4,213 with a sample standard deviation σ_s of 2,473. The visual system data base cost was computed in the visual system section. The flow diagram also subtracts from the program size if the motion system is not included. The sample mean $\mu_{\bar{x}}$ for the motion system is 782 with a standard deviation σ_s of 359. When estimating for two to four trainee stations, the result of one trainee station will be multiplied. The result will be multiplied by two if two trainee stations, by three if three trainee stations and by four if four trainee stations. Only one trainee station will be configured with a visual system. The total program size is converted to a cost estimate by using equation 22. Equation 22 cost estimates include all programming activities such as program design, program coding, program testing or checkout, and program documentation.



NOTE: Program size includes number of instructions, constants and data storage. Word size is from 24 to 32 bit.

Fig. 11. Flow Diagram for Determining Computer Program Size of One Trainee Station

Costing and Pricing An Operational Flight Trainer System Design

The following procedures are to be used in costing and pricing out the Operational Flight Trainer (OFT) system design element of the Work Breakdown Structure (WBS).[10] From the previous functional cost estimating techniques the decision-maker must determine the most feasible technical approaches that may be used to realize each subsystem. Probabilities are then assigned to each approach according to the likelihood of that approach actually being taken.

Trainee station(s) and instructor station(s) material costs would be derived from Table 8 or from equation 4 and equation 12. Equation 19 combines both the trainee and instructor stations cost since the instructor station material cost is dependent upon the material cost of the student station:

$$CS_{ij} = [[[(EN_{ij})(E)(1 + OH)](1 + G)](1 + P)] + [[[(MF_{ij})(N)(M)(1 + OH)](1 + G)](1 + P)] + [[(MA_{ij})(1 + G)](1 + P)]$$

(Equation 17)

where

CS_{ij} is the cost of trainee station(s) i using approach j.

EN_{ij} is the engineering hours for Work Breakdown Structure (WBS) element i using approach j.

For trainee station use computed data at end of trainee station section. For instructor station use computed data at end of instructor station section.

MF_{ij} is the manufacturing hours for either trainee station or instructor station i using approach j.

Trainee station will use computed data at the end of trainee station section. Instructor station will use computed data at end of section on instructor station.

N is the number of trainee stations or instructor stations to be manufactured.

MA_{ij} is the material cost for subsystem i using approach j.

When computing for trainee station use either equation 4 or Table 8. Instructor station will use equation 12 or Table 8.

E is the engineering labor rate. Use Table 13.

M is the manufacturing labor rate. Use Table 13.

OH is the appropriate overhead rate. Use Table 13.

G is the general and administrative rate. Use Table 13.

P is an estimate of the contractor profit rate (Usually 10 percent). This variable to be left out when computing cost variable for system integration.

TABLE 13

LABOR RATE COST DATA FOR

FISCAL YEAR 1976[11]

Engineering Labor Rate	8.25
Engineering Overhead	110%
Manufacturing Labor Rate	5.30
Manufacturing Overhead	150%
General and Administrative Rate	16%
Profit Cost Type	7% - 10%
Profit Fixed Price	12% - 15%
Profit Other Than Fixed Price	9% - 12%

$$CI_{ij} = [[[(EN_{ij}) (E) (1 + OH)] (1 + G)] (1 + P)] + [[[(MF_{ij}) (N) (M) (1 + OH)] (1 + G)] (1 + P)] + [[(MA_{ij}) (1 + G)] (1 + P)]$$

(Equation 18)

CI_{ij} is the cost of instructor station(s) i using approach j.

The combined student and instructor station cost is $CT_{ij} = CS_{ij} + CI_{ij}$ (Equation 19)

CT_{ij} is the total combined cost of student station and instructor station i using approach j.

If P variable is left out CT_{ij} would be cost without profit variable.

The total cost of motion systems would be resolved from the below equation:

$$CM_{ij} = (\text{Number of Trainee Stations})\,(MSC_{ij})\,(1 + P) \qquad \text{(Equation 20)}$$

CM_{ij} is the total cost of motion system i using approach j.

MSC_{ij} is the cost of a single motion system i using approach j.

This cost includes engineering, manufacturing labor, material, overhead cost, general, and administrative expenses and can be computed from equation 14.

The cost of computer hardware would be determined from the below equation:

$$CC_{ij} = [CH_{ij}]\,(1 + P) \qquad \text{(Equation 21)}$$

where

CC_{ij} is the total cost with manufacturing profit added of the computer hardware system(s) i using approach j.

CH_{ij} is the cost of computer hardware system(s) i using approach j.

This cost includes engineering, manufacturing labor, material, overhead cost, general, and administrative expenses and can be computed from Figure 9.

The cost of computer software can be determined from the below equation:

$$CP_{ij} = [[(X)\ (PI_{ij})\ (E)\ (1 + OH)]\ (1 + G)]\ (1 + P)] \qquad \text{(Equation 22)}$$

where

CP_{ij} is the cost of computer(s) software i using approach j.

X is a variable use in calibrating the number of trainers. If one trainer is configured, X will equal .9. If two or three trainers are configured, then X will equal 0.75. If four trainers are configured, X would equal .60.

PI_{ij} is the computer(s) software program size i using approach j, which would be estimated from Figure 11.

The visual system cost would be computed from the below equation:

$$CX_{ij} = (CV_{ij})\ (1 + \ ) \qquad \text{(Equation 23)}$$

where

CX_{ij} is the cost of visual system i using approach j.

CV_{ij} is the cost of visual system i using approach j.

This cost includes engineering, manufacturing labor, material, overhead cost, general and administrative expenses, and can be computed from Figure 10.

System integration cost is to be computed according to the following procedure: [12]

$$\text{System Integration Cost} = \begin{bmatrix}\text{Visual System}\\ \text{Total Cost}\end{bmatrix}[.15] + \begin{bmatrix}\text{Motion System}\\ \text{Total Cost}\end{bmatrix}[.10] + \begin{bmatrix}\text{Trainee Station \&}\\ \text{Instructor Station}\\ \text{Total Cost}\end{bmatrix}[.10] + \begin{bmatrix}\text{Computer Hardware}\\ \text{Total Cost}\end{bmatrix}[.15]$$

(Equation 24)

Trainee station and instructor station total costs are equations 17, 18 and 19 without the profit variable. Motion system(s) total cost is equation 20 without the profit variable. Computer hardware total cost is determined from Figure 9. The visual system total cost is CV and is derived from Figure 11.

The system integration percentage factors for the fourth level Work Breakdown Structure (WBS) elements can be determined by using the technique of weighting objectives as described in Chapter 6 of <u>Introduction To Operation Research</u> by C. W. Churchman, R. L. Ackoff, and

E. L. Arnoff. Each project or system engineer at the NAVTRAEQUIPCEN would, in making his own estimate, establish the relative values (weights) to each fourth level Work Breakdown Structure (WBS) element and from these values decide what percentage to be used in estimating system integration cost.

CHAPTER VI

INFLATION FORECASTING AS APPLIED TO OPERATIONAL FLIGHT TRAINERS

Inflationary forecasting as applied to Operational Flight Trainers (OFT's) for fiscal year 1976 were predetermined by the memorandum from the Director of Procurement Services Department of the Naval Training Equipment Center dated 15 March 1976.[13] The 1976 fiscal year was from 1 July 1975 calendar year to 30 June 1976 calendar year. From 1 July 1976 calendar year to 30 September 1976 calendar year a new fiscal year reporting system was established within the U. S. Government. This short time period was recorded as fiscal year 197T.

The 1977 fiscal year was from 1 October 1976 to 30 September 1977. All preceding fiscal years are now recorded from 1 October to 30 September. The escalation factors for labor and material for FY77 is 10 percent. Fiscal year 1978 escalation factors for labor and material are 7.0 percent. All fiscal years preceding 1978 will be 6.5 percent. Overhead and G&A rates would increase at approximately 2.0 percent per year.[14]

Table 14 was developed using data from the referenced Director of Procurement Services memorandum.

TABLE 14

INFLATIONARY INDEX

Fiscal Year	Labor and Material	Overhead G&A
1976 (Base)	1.0	1.0
1977	1.1	1.02
1978	1.17	1.04
1979	1.25	1.06
1980	1.33	1.08
1981	1.42	1.10
1982	1.51	1.12
1983	1.61	1.14
1984	1.71	1.17
1985	1.83	1.19

The application of forecasting inflation using Table 14 would be to take the material cost for trainee station from either equation 4 or Table 4 and project it to fiscal year 1985 by multiplying it by 1.83. Example would be the material cost inflationary forecast for three trainee stations in fiscal year 1985 using equation 4.

$$[26885.76 + 94824.63(3)]\ (1.83) = \$569{,}799$$

Using Table 13 data and forecasting for inflation to fiscal year 1985,

Engineering Labor Rate	\$8.25 (1.85) = \$15.26
Engineering Overhead	1.10 (1.19) = 130%
Manufacturing Labor Rate	\$5.30 (1.85) = \$9.80
Manufacturing Overhead	1.5 (1.19) = 178%
General and Administrative Rate	.16 (1.19) = 19%

Using equation 17, trainee station engineering and manufacturing data from Chapter V and a profit fixed price of 15 percent, the estimated average cost for three trainee stations in fiscal year 1985 would be

$$CS = [[[(13{,}674)(15.26)(2.3)](1.19)(1.15)] + [[(4{,}310)(3)(9.8)(2.78)](1.19)(1.15)] + [(569{,}788)(1.19)(1.15)]$$

$$CS = \$1{,}918{,}614$$

CHAPTER VII

CONCLUSIONS

This research paper has presented and explained functional cost estimating techniques that apply to the system design Work Breakdown Structure (WBS) of an Operational Flight Trainer (OFT). The system design work breakdown elements that this paper directed itself to were as follows:

1. Trainee Stations
2. Instructor Stations
3. Motion System
4. Visual System
5. Computer System Hardware
6. Computer System Software
7. System Integration

The methods used in this paper to determine the functional cost estimating techniques were as follows:

1. Linear regression analysis of sample data.
2. Linear multivariate analysis of sample data.
3. Measure of central tendency and dispersion of sample data.

4. Test of significance for small univariate samples using student's t distribution.

5. Estimating the confidence limits for hypothetical population mean μ from a small sample using student's t distribution.

6. Naval Training Equipment Center "expert" opinion on estimating low cost, most likely cost and high cost on computer hardware and visual systems selections.

The functional cost estimating technique developed in this research paper have not yet been practically applied to real problems. Current methods at the Naval Training Equipment Center rely on previous cost experience and intuition. The methods presented here will add substance to cost verification that is not dependent upon personal experience.

The results of this research paper are that a cost/price for each Work Breakdown Structure (WBS) element can be made separately and appraised, or totalled into the system design Work Breakdown Structure (WBS) element and evaluated. Also, inflationary cost can be examined and judged from fiscal year to fiscal year using data in Chapter VI. If time had permitted, further area of research would have been to develop an interactive computer program that would accept additional data and integrate each cost/price estimating technique into total cost/ price system for an Operational Flight Trainer (OFT).

The author acknowledges that data in Table 8 assumes that the variance for student station material cost does not effect the variances for instructor station material cost. Future work in this area would include combining the two variances for determining a much broader confidence interval for instructor station material cost. Future effort would also include examining other CER's on Operational Flight Trainers (OFT's) that would provide a refinement in estimating cost. This would include such factors as physical descriptions (weight and size), specifications and reliability factors, quantities (prototype and production), performance schedules (engineering and production), design inventory, cost/ quantity relationship (learning curve), and integration and test requirements. The output of this proposed model could then provide empirical values, schedule effects (engineering/production interaction), integration and test costs (all Work Breakdown Structure (WBS) levels) and many other areas that could provide a detail model relationship of each functional area.

APPENDIX A

COMPUTER DATA RUN FOR MOTION SYSTEM USING STEPWISE LINEAR REGRESSION MODEL

80 COLUMN ALL-PURPOSE WORKSHEET (Key punch)
CHET-GEN 5000/11 (1-74)

EXAMPLE OF INPUT FOR STEPWISE REGRESSION TO ESTIMATE MOTION SYSTEM COST USING DUMMY VARIABLES

PROGRAM: STEPWISE REGRESSION PROGRAMMER: PAGE NO. 1 OF 1 DATE: 11 Feb 1977

```
PROBLM   MOTION   11   13    0    0         1    9 YES YES YES          1
LABELS   2DEGFRE   3PAYLD    4TOTWT    5PITCH    6ROLL     7YAW      8VERTCL
LABELS   9LATRAL   10LONG
(F4.0,9F5.2,3F2.0)
 386  600 1824 3398 5000 4400 6400 6900 9600 9700 1 0 0
 268  600 1000 1000 5800 4800 5400 6800 7600 8100 1 0 0
 327  600 1824 1260 5000 4400 5800 5500 8400 9600 1 0 0
 218  400  840 1242 3000 3000  000 2400 3000  000 1 0 0
 149  300 1500 1500 3700 2600 3000 0000  000  000 1 0 0
 327  600 2000 2500 5600 6400 7000 6600 960010400 0 0 1
 238  600 1000 1250 4400 4400 5600 6900 8000 8600 0 0 1
 149  600  700 1200 5500 4400 4400 8400 5600 6400 0 0 1
*
*
 476  600 2000 4700 3600 3600 1800 6000 9600 4200 0 1 0
 595  600 2000 4700 5600 3800 2600 9600 9600 6900 0 1 0
 357  600  800 2400 5500 5400 6600 7500 8600 9400 0 0 0
SUBPRG   1          0.500     0.100              9       YES  YES
IDXPLT 2 3 4 5 6 7 8 9101112
FINISH
```

*Add More Data

BMD02R - STEPWISE REGRESSION - REVISED MARCH 27, 1973
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM CODE	MOTION
NUMBER OF CASES	11
NUMBER OF ORIGINAL VARIABLES	13
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	13
NUMBER OF SUB-PROBLEMS	1
THE VARIABLE FORMAT IS	(F4.0,9F5.2,3F2.0)

VARIABLE		MEAN	STANDARD DEVIATION
	1	319.09082	134.31631
DEGFRE	2	5.54545	1.03572
PAYLD	3	14.08000	5.41921
TOTWT	4	24.68181	13.83760
PITCH	5	47.90909	9.68973
ROLL	6	42.90909	10.99674
YAW	7	43.63635	22.41101
VERTCL	8	59.72726	26.82941
LATRAL	9	72.36363	31.50639
LONG	10	66.63635	37.43063
	11	0.45455	0.52223
	12	0.18182	0.40452
	13	0.27273	0.46710

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	18040.875	67.245	473.751	1685.725	273.609	161.909	-160.564	1974.526	3032.962	1526.535
2		1.073	0.860	5.357	6.858	7.655	12.818	28.064	30.182	33.318
3			29.324	60.203	1.584	2.136	7.288	12.080	72.752	36.968
4				191.479	8.320	-2.570	-23.675	143.974	264.635	105.989
5					93.891	76.691	161.964	200.473	171.036	290.463
6						112.291	195.964	166.673	218.836	339.364
7							302.254	245.091	346.745	731.453
8								719.817	685.509	729.490
9									992.653	967.744
10										1401.093

VARIABLE NUMBER	11	12	13
1	-22.749	43.282	-24.327
2	-0.273	0.091	0.136
3	-0.052	1.184	-0.524
4	-1.941	4.464	-2.455
5	-1.455	-0.382	1.127
6	-2.255	-1.182	2.327
7	-1.218	-4.327	3.309
8	-8.264	3.685	3.082
9	-7.582	4.727	1.491
10	-5.918	-2.227	5.409
11	0.273	-0.091	-0.136
12		0.164	-0.055
13			0.218

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	1.000	0.483	0.651	0.907	0.712	0.114	-0.053	0.548	0.717	0.304
2		1.000	0.153	0.374	0.683	0.697	0.552	0.902	0.925	0.859
3			1.000	0.803	0.030	0.037	0.060	0.083	0.426	0.182
4				1.000	0.062	-0.018	-0.076	0.388	0.607	0.205
5					1.000	0.747	0.746	0.771	0.560	0.801
6						1.000	0.825	0.586	0.655	0.856
7							1.000	0.408	0.491	0.872
8								1.000	0.811	0.726
9									1.000	0.821
10										1.000

VARIABLE NUMBER	11	12	13
1	-0.324	0.797	-0.388
2	-0.504	0.217	0.282
3	-0.018	0.541	-0.207
4	-0.269	0.797	-0.380
5	-0.287	-0.097	0.249
6	-0.407	-0.276	0.470
7	-0.104	-0.477	0.316
8	-0.590	0.337	0.246
9	-0.461	0.371	0.101
10	-0.303	-0.147	0.309
11	1.000	-0.430	-0.559
12		1.000	-0.289
13			1.000

```
SUBPROBLEM      1
 DEPENDENT VARIABLE                1
 MAXIMUM NUMBER OF STEPS          26
 F-LEVEL FOR INCLUSION     0.560000
 F-LEVEL FOR DELETION      0.100000
 TOLERANCE LEVEL           0.001000
```

```
STEP NUMBER    1
VARIABLE ENTERED     4

MULTIPLE R              0.9070
STD. ERROR OF EST.     59.6309

ANALYSIS OF VARIANCE
                   DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
    REGRESSION      1      148406.060      148406.060     41.736
    RESIDUAL        9       32002.574        3555.842
```

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	101.79765)		
JOINT 4	8.80310	1.36273	41.7359 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGREE 2	0.36758	0.8603	1.2636 (2)
PAYLD 3	-0.30841	0.3545	0.8409 (2)
PITCH 5	0.36975	0.9761	1.2667 (2)
ROLL 6	0.30788	0.9937	0.9377 (2)
YAW 7	0.03787	0.9742	0.0115 (2)
VERTCL 8	0.50538	0.8496	2.7442 (2)
LATRAL 9	0.49646	0.6316	2.6167 (2)
LONG 10	0.28632	0.9581	0.7144 (2)
11	-0.19885	0.9779	0.3293 (2)
12	0.28861	0.3641	0.7269 (2)
13	-0.11120	0.8558	0.1002 (2)

```
STEP NUMBER    2
VARIABLE ENTERED     8

MULTIPLE R              0.9316
STD. ERROR OF EST.     54.5786

ANALYSIS OF VARIANCE
                   DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
    REGRESSION      2      156579.810       78289.875     26.284
    RESIDUAL        8       23828.832        2978.604
```

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	54.20490)		
JOINT 4	7.93443	1.35312	34.3842 (2)
VERTCL 8	1.15609	0.69789	2.7442 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGREE 2	-0.17430	0.1858	0.2746 (2)
PAYLD 3	-0.12497	0.2731	0.1111 (2)
PITCH 5	-0.08070	0.3373	0.0457 (2)
ROLL 6	-0.02424	0.5857	0.0048 (2)
YAW 7	-0.26688	0.7692	0.5368 (2)
LATRAL 9	0.18615	0.2416	0.2513 (2)
LONG 10	-0.12458	0.4655	0.1140 (2)
11	0.10741	0.6503	0.0817 (2)
12	0.30589	0.3632	0.7226 (2)
13	-0.44958	0.6738	1.7782 (2)

STEP NUMBER 3
VARIABLE ENTERED 13

MULTIPLE R 0.9458
STD. ERROR OF EST. 52.1160

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	161396.120	53798.707	19.807
RESIDUAL	7	19012.551	2716.079	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		68.93869)		
TOTWT	4	6.85398	1.52574	20.1801 (2)
VERTCL	8	1.61724	0.75103	4.6369 (2)
	13	-57.23640	42.98209	1.7732 (2)

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGREE	2	-0.11553	0.1778	0.0812 (2)
PAYLD	3	0.10205	0.2316	0.0631 (2)
PITCH	5	-0.16926	0.3313	0.1770 (2)
ROLL	6	0.12803	0.5327	0.1000 (2)
YAW	7	-0.24112	0.7585	0.3706 (2)
LATRAL	9	0.29393	0.2353	0.5674 (2)
LONG	10	-0.06173	0.4539	0.0245 (2)
	11	-0.28118	0.3678	0.5151 (2)
	12	0.34391	0.3632	0.8048 (2)

STEP NUMBER 4
VARIABLE ENTERED 12

MULTIPLE R 0.9524
STD. ERROR OF EST. 52.8581

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	163644.790	40911.198	14.643
RESIDUAL	6	16763.887	2793.981	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		94.40989)		
TOTWT	4	5.44057	2.20836	6.0693 (2)
VERTCL	8	1.58815	0.76242	4.3391 (2)
	12	61.50816	68.56192	0.8048 (2)
	13	-57.34993	43.59430	1.7306 (2)

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGREE	2	0.03227	0.1470	0.0052 (2)
PAYLD	3	0.23906	0.2076	0.3031 (2)
PITCH	5	0.00026	0.2509	0.0000 (2)
ROLL	6	0.48205	0.3148	1.5135 (2)
YAW	7	0.07452	0.2476	0.0274 (2)
LATRAL	9	0.53588	0.1875	2.0143 (2)
LONG	10	0.39981	0.1516	0.9513 (2)
	11	-0.11878	0.2582	0.0716 (2)

STEP NUMBER 5
VARIABLE ENTERED 9

MULTIPLE R 0.9663
STD. ERROR OF EST. 48.8873

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	5	168458.810	33691.762	14.097
RESIDUAL	5	11949.863	2389.973	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	107.11307)		
TOTWT 4	2.93516	2.69962	1.1821 (2)
VERTCL 8	0.37173	1.10988	0.1122 (2)
LATRAL 9	1.60873	1.13351	2.0143 (2)
12	107.00116	71.05275	2.2679 (2)
13	-67.97278	41.00839	2.7474 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGFRE 2	-0.91802	0.0429	21.4390 (2)
PAYLD 3	0.15813	0.1992	0.1076 (2)
PITCH 5	0.11489	0.2430	0.0535 (2)
ROLL 6	0.24209	0.2044	0.2490 (2)
YAW 7	-0.14542	0.2161	0.0864 (2)
LONG 10	-0.02034	0.0625	0.0017 (2)
11	-0.14403	0.2582	0.0847 (2)

STEP NUMBER 6
VARIABLE ENTERED 2

MULTIPLE R 0.9948
STD. ERROR OF EST. 21.6736

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	6	178529.680	29754.945	63.343
RESIDUAL	4	1878.981	469.745	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	589.60766)		
DEGFRE 2	-147.93549	31.94987	21.4391 (2)
TOTWT 4	0.81113	1.28174	0.4005 (2)
VERTCL 8	2.48335	0.67089	13.7016 (2)
LATRAL 9	5.23382	0.93027	31.6500 (2)
12	99.26210	31.54466	9.9018 (2)
13	-55.93939	18.36537	9.2776 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
PAYLD 3	-0.16936	0.1874	0.0886 (2)
PITCH 5	-0.14182	0.2346	0.0616 (2)
ROLL 6	-0.25057	0.1772	0.2010 (2)
YAW 7	-0.38406	0.2161	0.5191 (2)
LONG 10	0.13197	0.0621	0.0532 (2)
11	0.02222	0.2511	0.0015 (2)

STEP NUMBER 7
VARIABLE ENTERED 7

MULTIPLE R 0.9956
STD. ERROR OF EST. 23.1072

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	7	178806.810	25543.828	47.840
RESIDUAL	3	1601.831	533.944	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		591.40706)		
DEGREE	2	-148.11914	34.06418	18.9072 (2)
TOTWT	4	1.17360	1.45620	0.6495 (2)
YAW	7	-0.50534	0.70141	0.5191 (2)
VERTCL	8	2.58284	0.77848	12.5708 (2)
LATRAL	9	5.38546	1.01397	28.2094 (2)
	12	70.21950	52.49808	1.7891 (2)
	13	-53.78646	19.80679	7.3743 (2)

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
PAYLD	3	-0.00613	0.1531	0.0001 (2)
PITCH	5	0.35249	0.0702	0.2837 (2)
ROLL	6	-0.06475	0.1294	0.0084 (2)
LONG	10	0.91664	0.0180	10.5185 (2)
	11	-0.07238	0.2362	0.0127 (2)

STEP NUMBER 8
VARIABLE ENTERED 10

MULTIPLE R 0.9993
STD. ERROR OF EST. 11.3118

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	8	180152.750	27519.094	175.990
RESIDUAL	2	255.913	127.957	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		674.61840)		
DEGREE	2	-156.71188	16.88477	86.1418 (2)
TOTWT	4	0.88776	0.71829	1.5275 (2)
YAW	7	-2.24848	0.63781	12.4287 (2)
VERTCL	8	2.11775	0.38437	30.3565 (2)
LATRAL	9	4.21204	0.61424	47.0230 (2)
LONG	10	2.31029	0.71234	10.5185 (2)
	12	111.13445	28.62903	15.0690 (2)
	13	-57.65228	9.76910	34.8276 (2)

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
PAYLD	3	-0.76010	0.1385	1.3683 (2)
PITCH	5	-0.17192	0.0565	0.0305 (2)
ROLL	6	0.61108	0.1152	0.5960 (2)
	11	-0.94162	0.2143	7.8376 (2)

STEP NUMBER 9
VARIABLE ENTERED 11

MULTIPLE R 0.9999
STD. ERROR OF EST. 5.3827

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	9	180379.680	20042.188	691.732
RESIDUAL	1	28.974	28.974	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		693.56665)		
DEGREE	2	-153.82087	8.10043	360.6277 (2)
TOTWT	4	1.00850	0.34451	8.5693 (2)
YAW	7	-2.59767	0.32814	62.6695 (2)
VERTCL	8	1.92327	0.19566	96.6226 (2)
LATRAL	9	3.99681	0.30223	174.8795 (2)
LONG	10	2.61388	0.35587	53.9371 (2)
	11	-19.70343	7.04028	7.8325 (2)
	12	95.89183	14.67155	42.7180 (2)
	13	-72.22780	6.98094	107.0487 (2)

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
PAYLD	3	1.00567	0.0175	0.0000 (2)
PITCH	5	1.00546	0.0427	0.0000 (2)
ROLL	6	1.00563	0.1050	0.0000 (2)

-LEVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

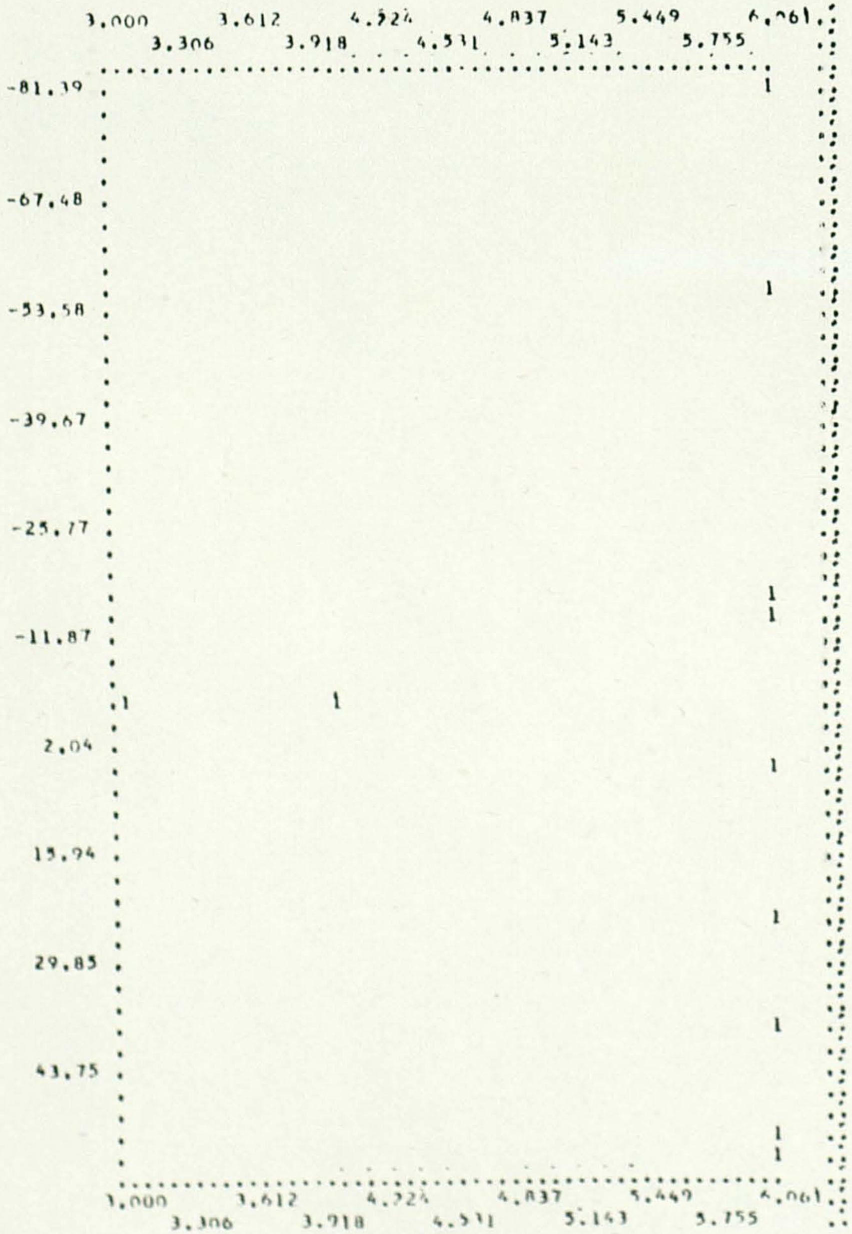
LY TABLE

P EP	VARIABLE ENTERED	REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
	TOTWT 4		0.9070	0.8226	0.8226	41.7359	1
	VERTCL 8		0.9316	0.8679	0.0453	2.7442	2
	13		0.9458	0.8946	0.0267	1.7732	3
	12		0.9524	0.9071	0.0125	0.8048	4
	LATRAL 9		0.9663	0.9338	0.0267	2.0143	5
	DEGREE 2		0.9948	0.9896	0.0558	71.4391	6
	YAW 7		0.9956	0.9911	0.0015	0.5191	7
	LONG 10		0.9993	0.9986	0.0075	10.5185	8
	11		0.9999	0.9998	0.0013	7.8325	9
13	9						

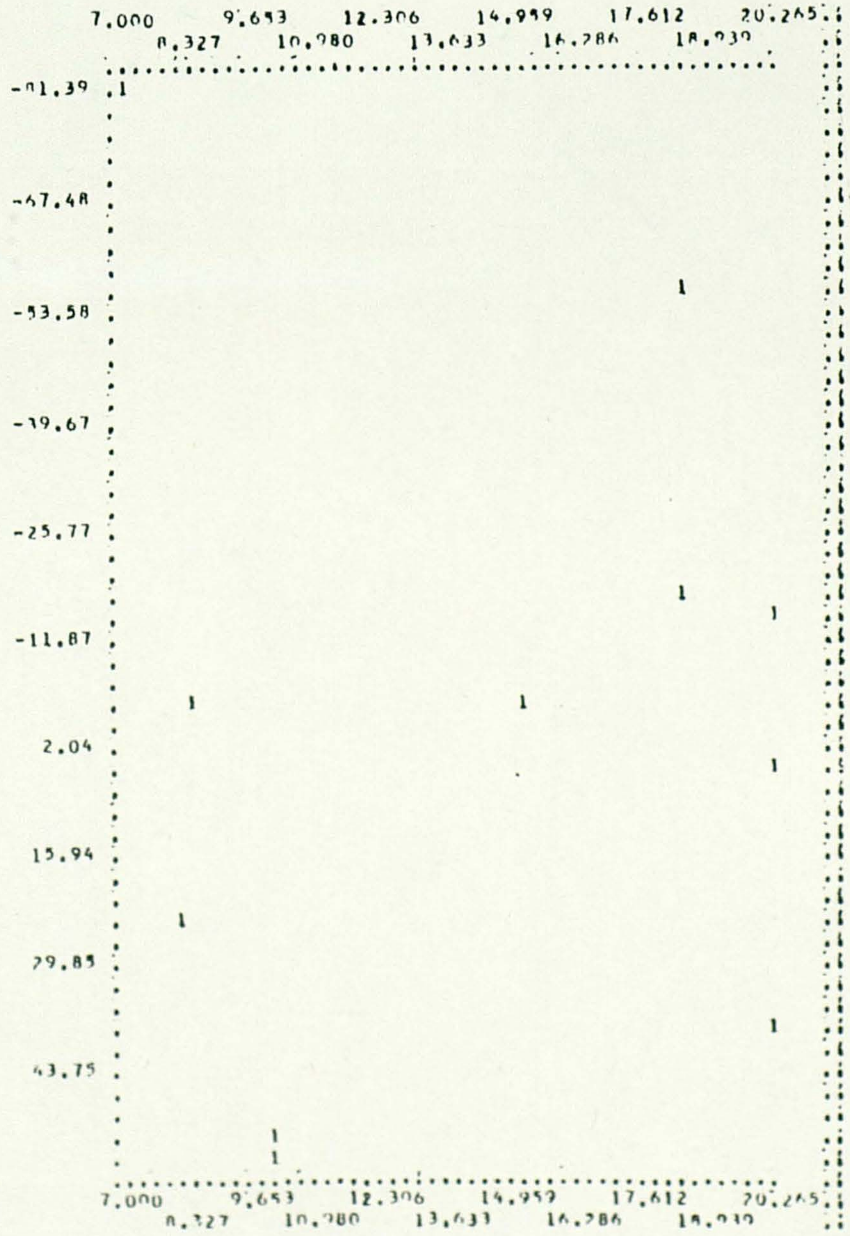
LIST OF RESIDUALS

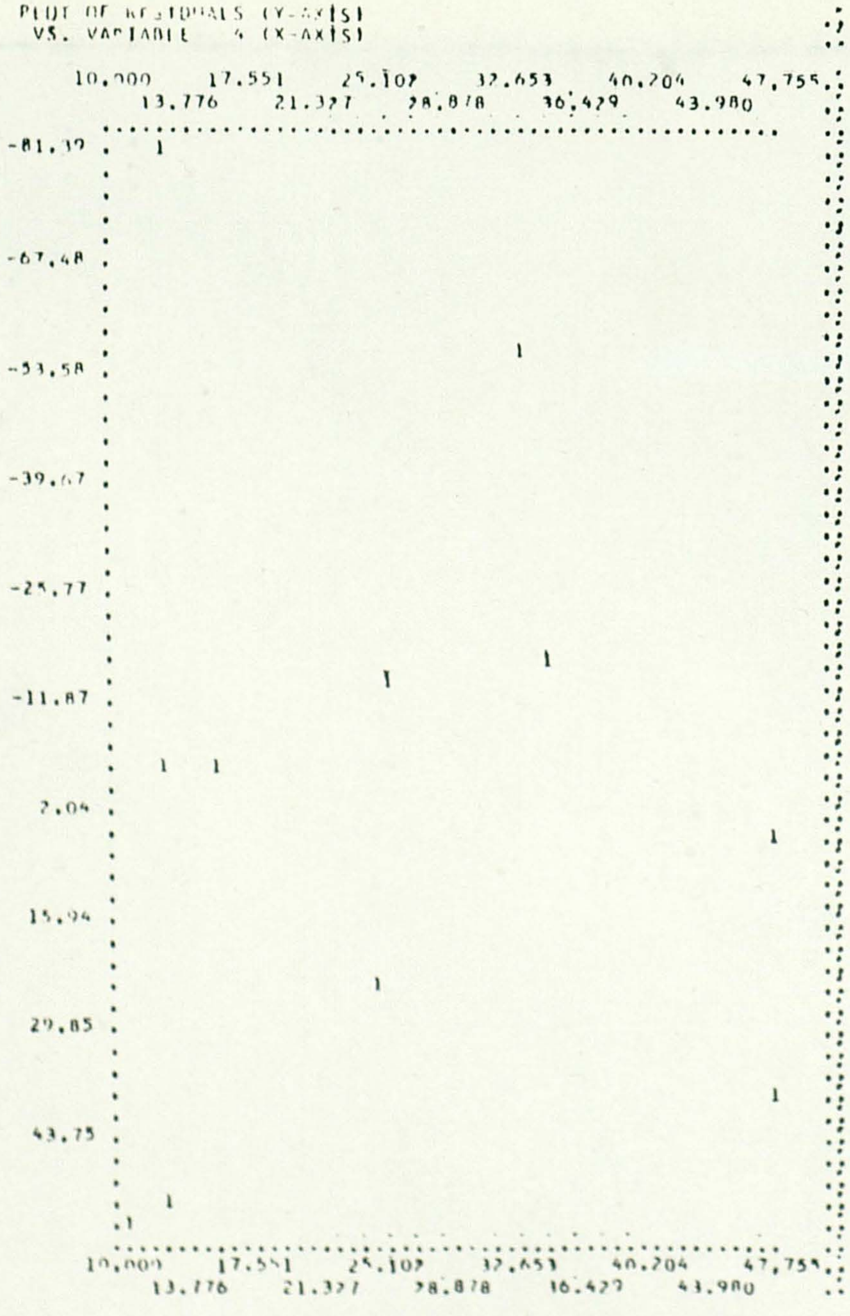
CASE NUMBER	Y X(1)	Y COMPUTED	RESIDUAL	X(4)	X(8)	X(5)
1	386.0000	403.9070	-17.9070	33.9800	69.0000	50.0000
2	268.0000	213.1237	54.8763	10.0000	68.0000	58.0000
3	327.0000	383.6055	-56.6055	32.6000	55.0000	50.0000
4	238.0000	240.4989	-2.4989	12.4200	240.0000	30.0000
5	149.0000	151.7907	-2.7907	15.0000	0.0000	37.0000
6	327.0000	340.7520	-13.7520	25.0000	66.0000	56.0000
7	238.0000	185.6774	52.3226	12.8000	60.0000	44.0000
8	149.0000	230.3888	-81.3888	12.0000	84.0000	55.0000
9	476.0000	470.7554	5.2446	47.0000	60.0000	36.0000
10	595.0000	555.9597	39.0403	47.0000	96.0000	56.0000
11	357.0000	333.5374	23.4626	24.0000	75.0000	55.0000

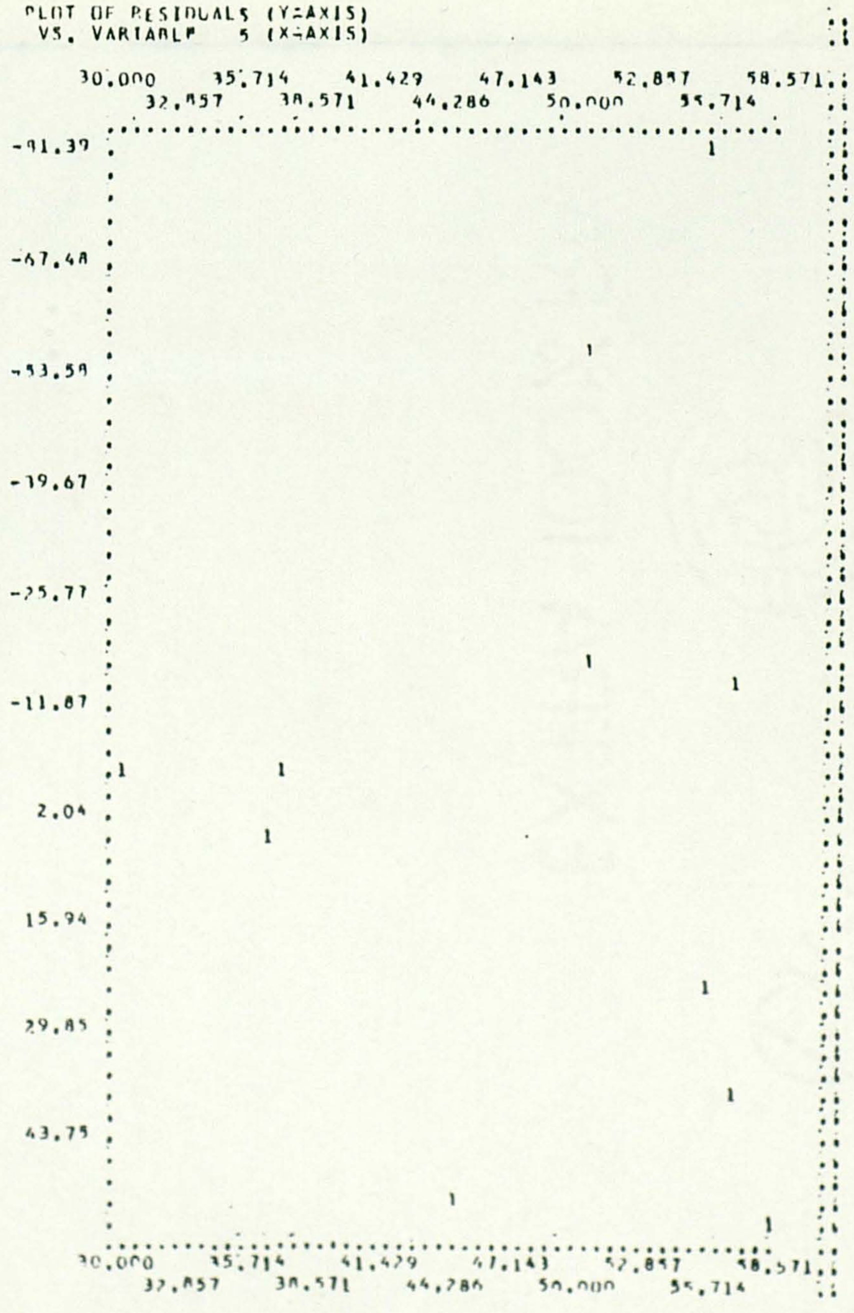
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)

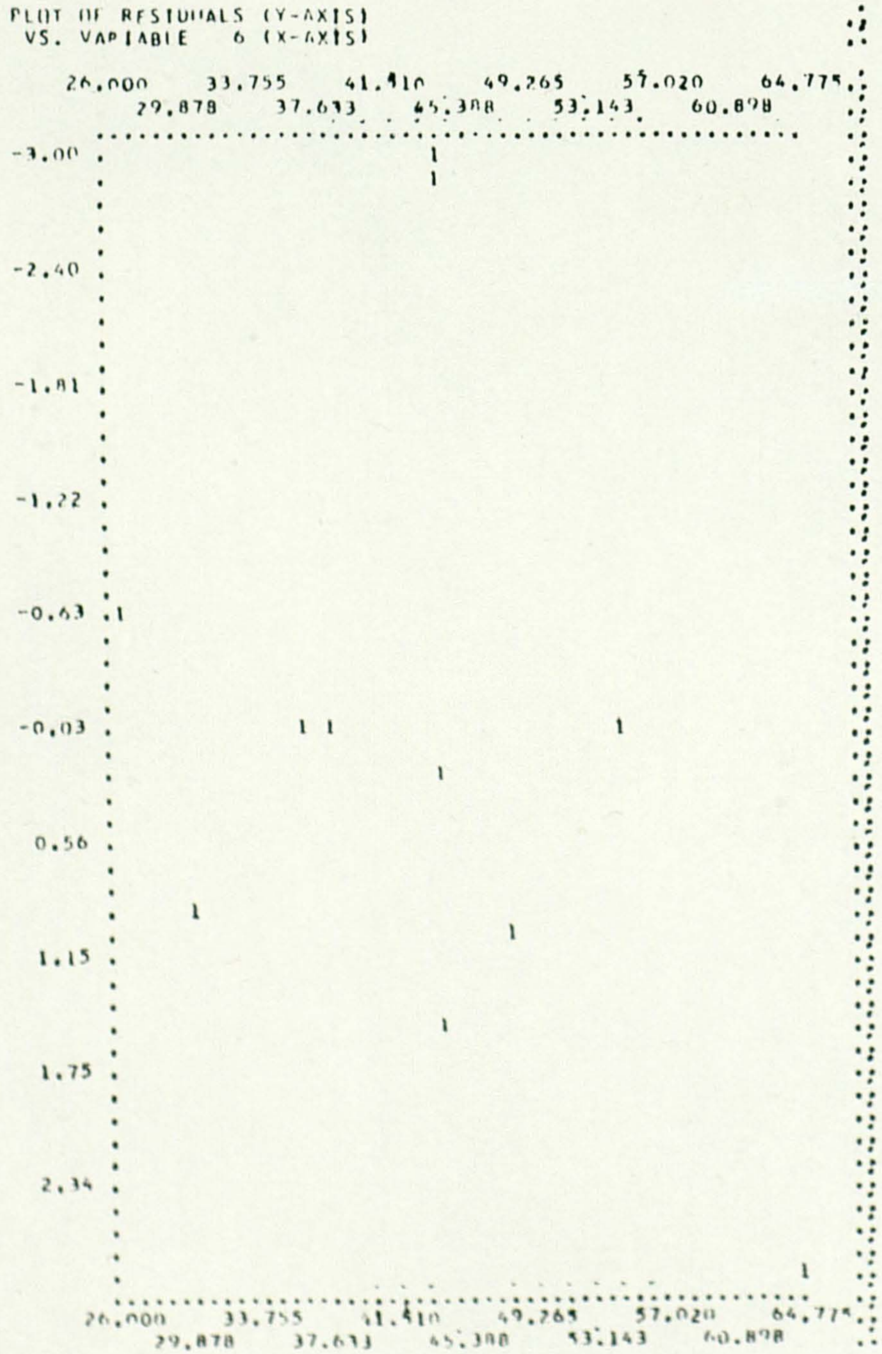


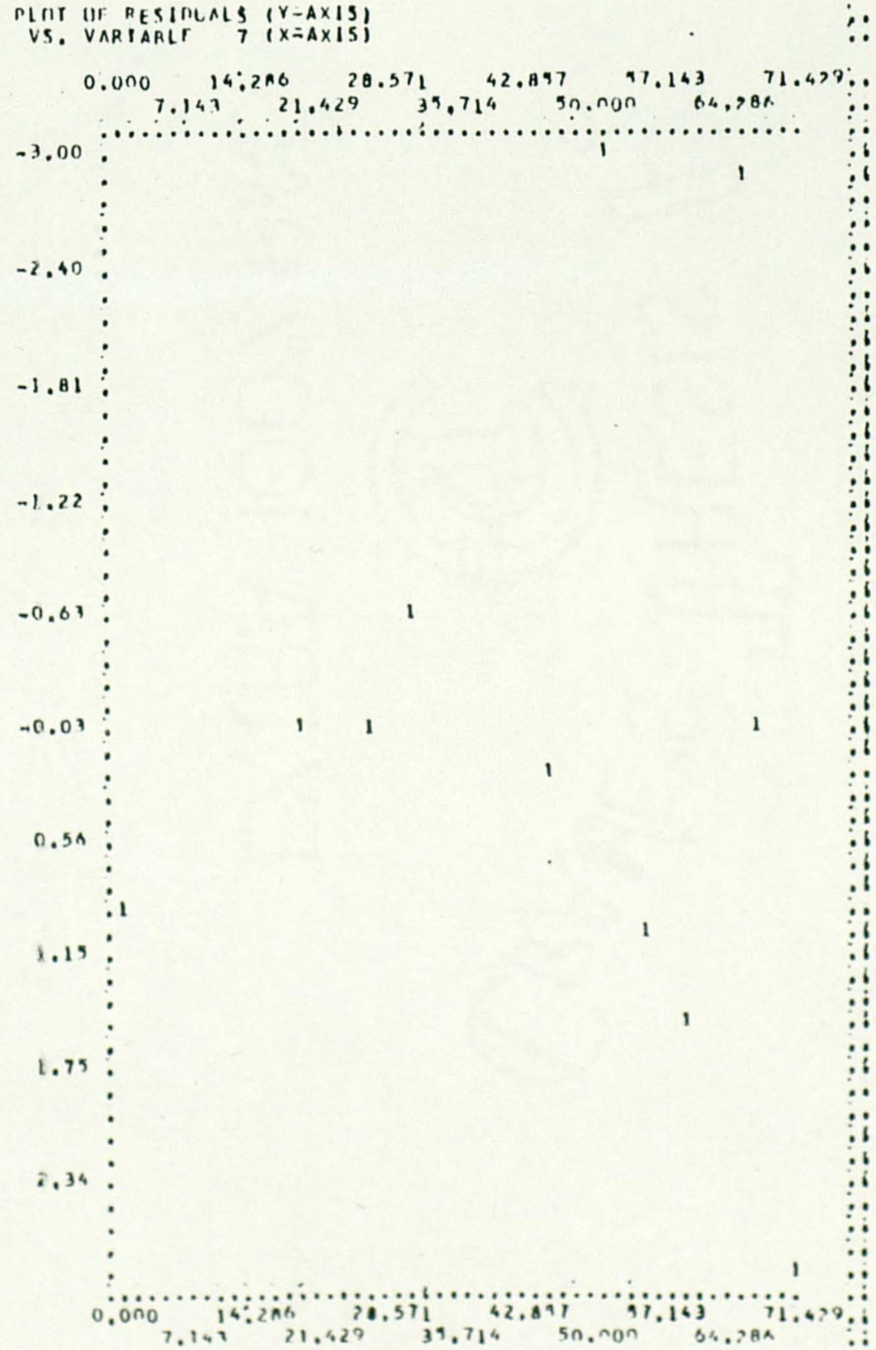
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



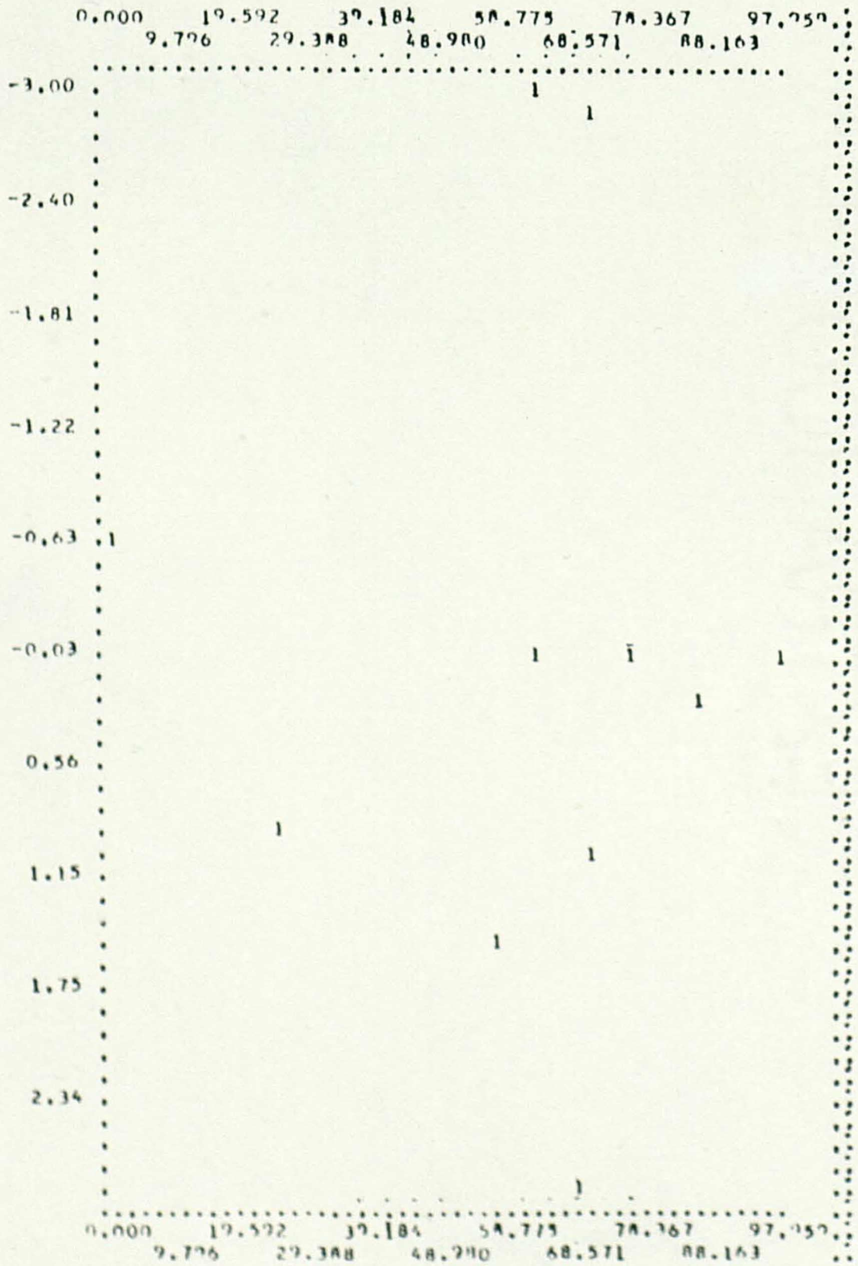

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)
10.000 17.551 25.102 32.653 40.204 47.755
13.776 21.327 28.878 36.429 43.980
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)
30.000 35.714 41.429 47.143 52.857 58.571
32.857 38.571 44.286 50.000 55.714
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75

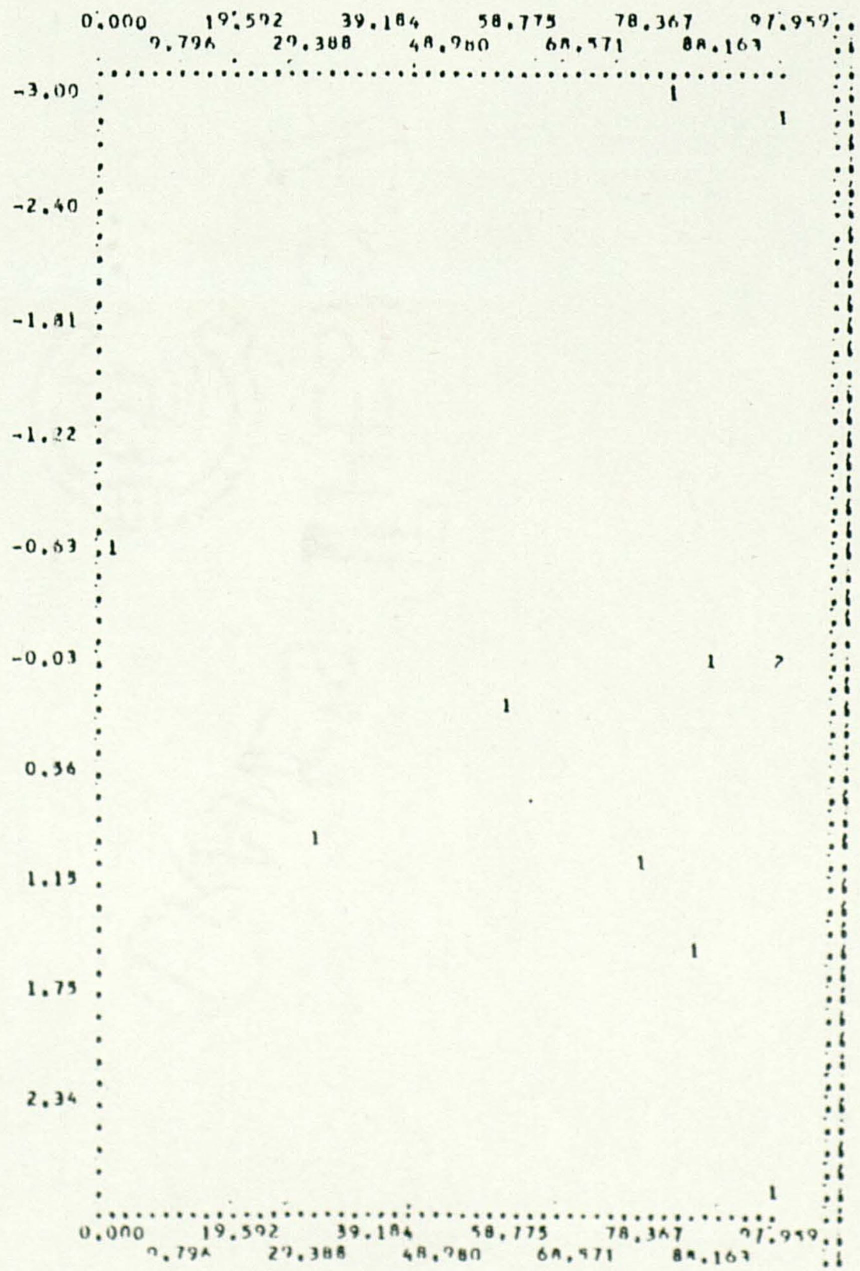

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 6 (X-AXIS)
26.000 33.755 41.510 49.265 57.020 64.775
29.878 37.633 45.388 53.143 60.898
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

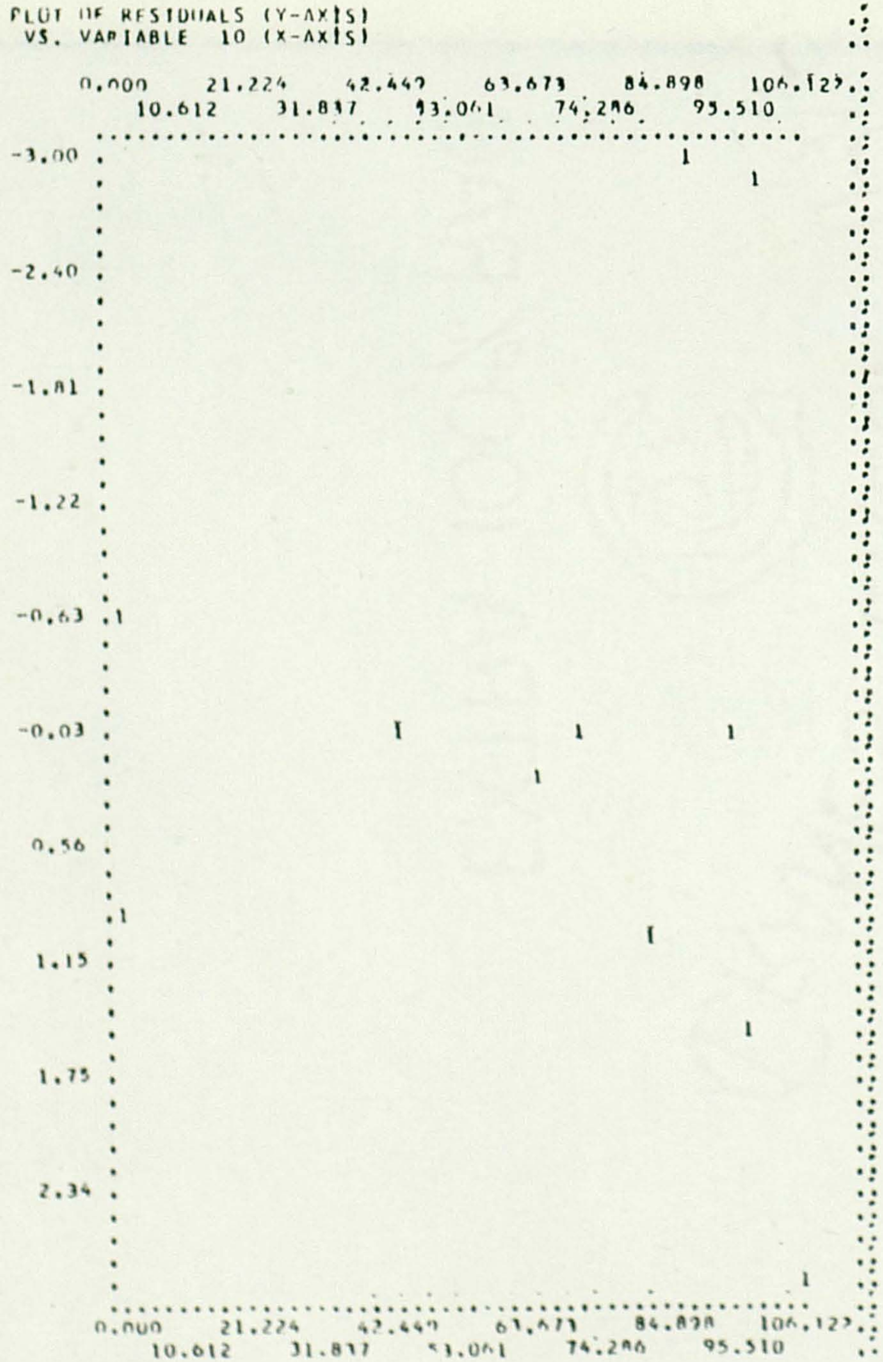

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 7 (X-AXIS)
0.000 14.286 28.571 42.857 57.143 71.429
7.143 21.429 35.714 50.000 64.286
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

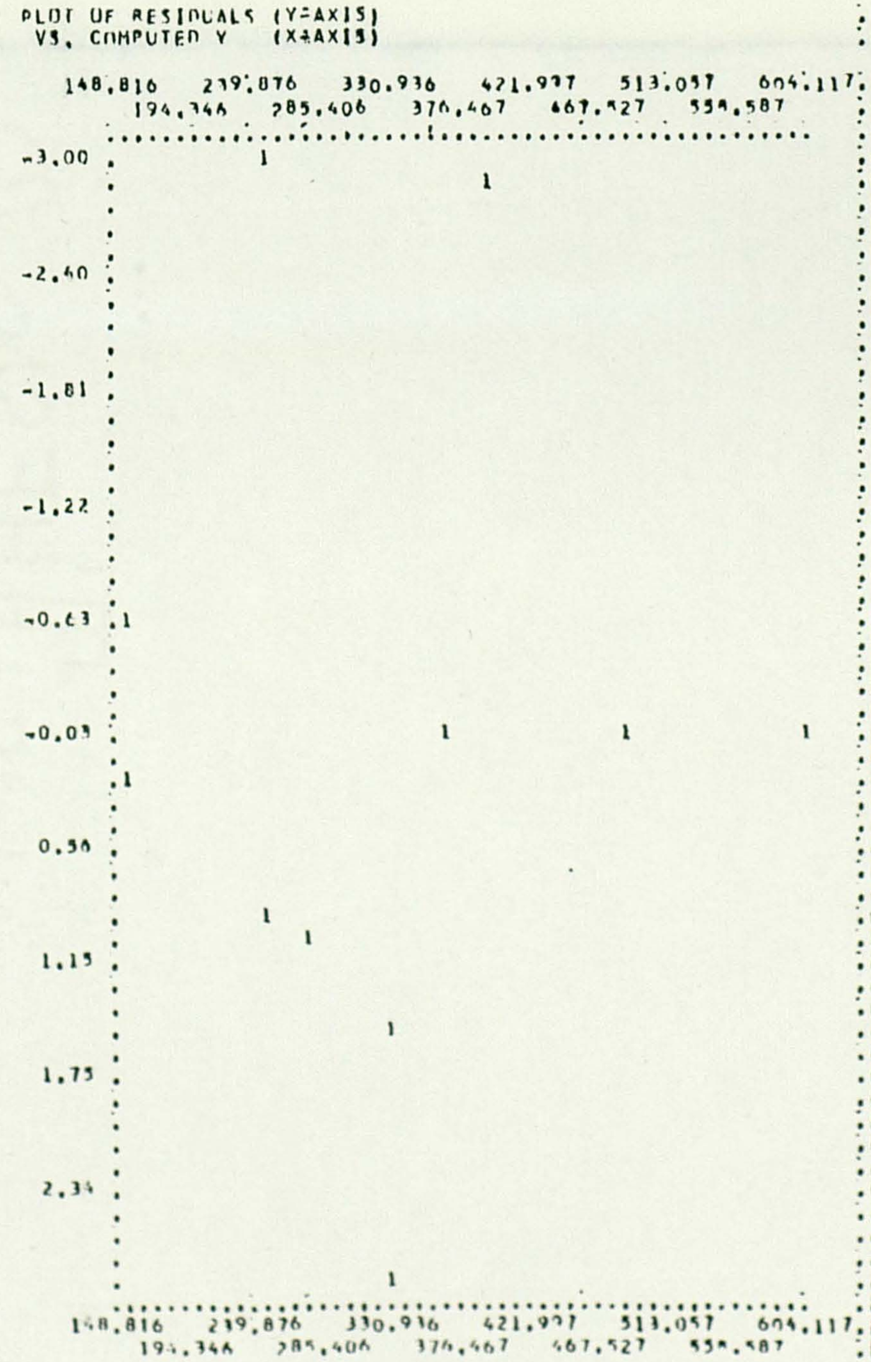
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 8 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 9 (X-AXIS)




PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 10 (X-AXIS)
0.000 21.224 42.449 63.673 84.898 106.122
10.612 31.837 53.061 74.286 95.510
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34


PLOT OF RESIDUALS (Y-AXIS)
VS. COMPUTED Y (X-AXIS)
148.816 239.876 330.936 421.997 513.057 604.117
194.346 285.406 376.467 467.527 558.587
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

MD02R - STEPWISE REGRESSION - REVISED MARCH 27, 1973
EALTH SCIENCES COMPUTING FACILITY, UCLA

ROBLEM CODE	MOTION
UMBER OF CASES	11
UMBER OF ORIGINAL VARIABLES	10
UMBER OF VARIABLES ADDED	0
OTAL NUMBER OF VARIABLES	10
UMBER OF SUB-PROBLEMS	1
HE VARIABLE FORMAT IS	(F4.0,9F5.2)

VARIABLE		MEAN	STANDARD DEVIATION
	1	319.09082	134.31631
DEGFRE	2	5.54545	1.03572
PAYLD	3	14.08000	5.41521
TOTWT	4	24.68181	13.83760
PITCH	5	47.90909	9.68973
ROLL	6	42.90909	10.39674
YAW	7	44.18181	22.65309
VERTCL	8	79.36363	58.46240
LATRAL	9	96.90909	73.02252
LONG	10	66.63635	37.43063

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10
1	18040.875	67.245	473.751	1685.725	275.609	161.909	-209.219	222.963	843.508	1526.535
2		1.073	0.860	5.357	6.058	7.655	13.091	-8.318	-11.545	33.318
3			29.324	60.203	1.984	2.136	4.840	-110.608	-80.608	36.968
4				191.479	8.328	-2.570	-30.984	-120.881	-66.434	105.989
5					93.891	76.691	159.618	-186.364	-312.509	290.463
6						112.291	196.618	-112.164	-129.709	339.364
7							513.163	-709.072	-841.380	743.071
8								3417.854	4107.633	-709.854
9									5332.289	-831.435
10										1401.053

ORRELATION MATRIX

RIABLE UMBER	1	2	3	4	5	6	7	8	9	10
1	1.000	0.483	0.651	0.907	0.212	0.114	-0.069	0.028	0.086	0.304
2		1.000	0.153	0.374	0.683	0.697	0.558	-0.137	-0.153	0.899
3			1.000	0.803	0.030	0.037	0.039	-0.349	-0.204	0.182
4				1.000	0.062	-0.018	-0.099	-0.149	-0.066	0.205
5					1.000	0.747	0.727	-0.329	-0.442	0.801
6						1.000	0.819	-0.181	-0.168	0.856
7							1.000	-0.535	-0.509	0.876
8								1.000	0.962	-0.324
9									1.000	-0.304
10										1.000

80 COLUMN ALL PURPOSE WORKSHEET *(key punch)*
CNET GEN 5000/11 (1-74),

EXAMPLE OF INPUT FOR STEPWISE REGRESSION TO DETERMINE MOTION SYSTEM COST WITHOUT USING DUMMY VARIABLES

PROGRAM: STEPWISE REGRESSION   PROGRAMMER: ____   PAGE NO. 1 OF 1   DATE: 10 February 1977

```
PROBLM   MOTION   11   10    0    0         1   9 YES YES YES          1
LABELS   2DEGFRE   3PAYLD    4TOTWT    5PITCH    6ROLL     7YAW      8VERTCL
LABELS   9LATRAL   10LONG
(F4.0,9F5.2)
 386  600 1824 3398 5000 4400 6400 6900 9600 9700
 268  600 1000 1000 5800 4000 5400 6000 7600 8100
 327  600 1824 3260 5000 4400 5800 5500 8400 9600
 218  400  840 1242 1000 1000  000 2400 3000  000
 149  100 1500 1500 1700 2600 1000 0000  000  000
 127  600 2000 2500 5600 6400 7000 6600 960010400
 218  600 1000 1250 4400 4400 5600 6000 8000 8600
 149  600  700 1200 5500 4400 4400 8400 5600 6400
*
*
 476  600 2000 4700 3600 3600 1800 6000 9600 4200
 595  600 2000 4700 5600 3800 2600 9600 9600 6900
 157  600  800 2400 5500 5400 6600 7500 8600 9400
SUBPRO   1          0.500     0.100              9       YES  YES
TDXFLT 2 3 4 5 6 7 8 910
FINISH
```

*Add More Data

```
SUB-PROBLM      1
 DEPENDENT VARIABLE            1
 MAXIMUM NUMBER OF STEPS      20
 F-LEVEL FOR INCLUSION     0.500000
 F-LEVEL FOR DELETION      0.100000
 TOLERANCE LEVEL           0.001000
```

```
STEP NUMBER     1
VARIABLE ENTERED     4

MULTIPLE R              0.9070
STD. ERROR OF EST.     59.6309
```

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	148406.060	148406.060	41.736
RESIDUAL	9	32002.574	3555.842	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	101.79965)		
TOTWT 4	8.80370	1.36273	41.7352 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGFRE 2	0.36758	0.8603	1.2636 (2)
PAYLD 3	-0.30841	0.3345	0.8409 (2)
PITCH 5	0.36975	0.9961	1.2669 (2)
ROLL 6	0.30788	0.9997	0.8377 (2)
YAW 7	0.04984	0.9902	0.0199 (2)
VERTCL 8	0.39361	0.9777	1.4667 (2)
LATRAL 9	0.34632	0.9957	1.0917 (2)
LONG 10	0.28632	0.9581	0.7144 (2)

```
STEP NUMBER     2
VARIABLE ENTERED     8

MULTIPLE R              0.9270
STD. ERROR OF EST.     58.1425
```

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	153364.250	76682.125	22.683
RESIDUAL	8	27044.438	3380.555	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	65.22682)		
TOTWT 4	9.04687	1.34380	45.3237 (2)
VERTCL 8	0.38520	0.31807	1.4667 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGFRE 2	0.44184	0.8535	1.6981 (2)
PAYLD 3	-0.18318	0.3007	0.2430 (2)
PITCH 5	0.57176	0.8216	3.3998 (2)
ROLL 6	0.42180	0.9652	1.5150 (2)
YAW 7	0.35410	0.6806	1.0041 (2)
LATRAL 9	-0.13911	0.0680	0.1381 (2)
LONG 10	0.46330	0.8698	1.9132 (2)

STEP NUMBER 3
VARIABLE ENTERED 5

MULTIPLE R 0.9482
STD. ERROR OF EST. 50.9948

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	162205.370	54068.457	20.792
RESIDUAL	7	18203.254	2600.465	

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-103.70325)		
TOTWT 4	9.01672	1.17872	58.5166 (2)
PITCH 5	3.24981	1.76250	3.3998 (2)
VERTCL 8	0.56133	0.29487	3.6240 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
DEGFRE 2	0.04760	0.4039	0.0136 (2)
PAYLD 3	-0.09745	0.2907	0.0575 (2)
ROLL 6	-0.00399	0.4344	0.0001 (2)
YAW 7	-0.09007	0.3371	0.0491 (2)
LATRAL 9	0.21844	0.0501	0.3006 (2)
LONG 10	0.02755	0.3326	0.0046 (2)

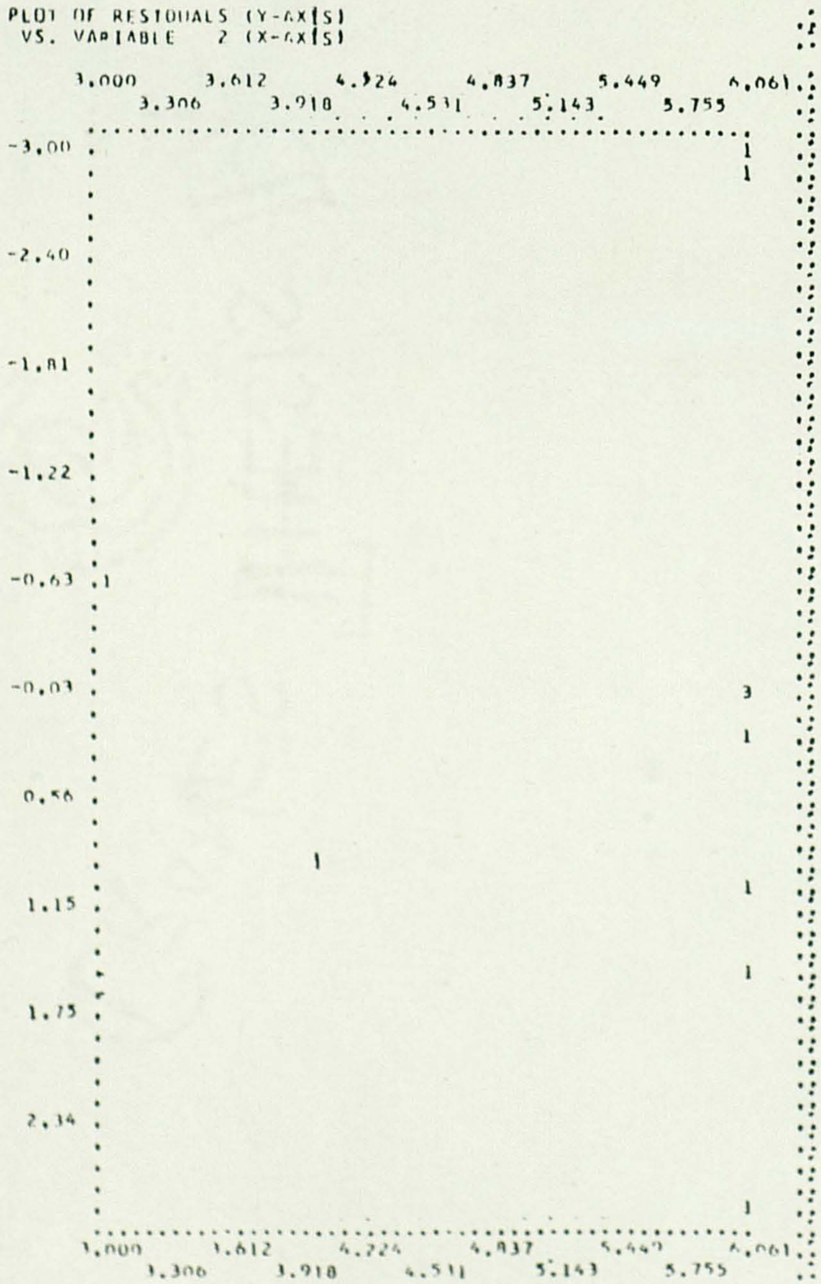
EVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

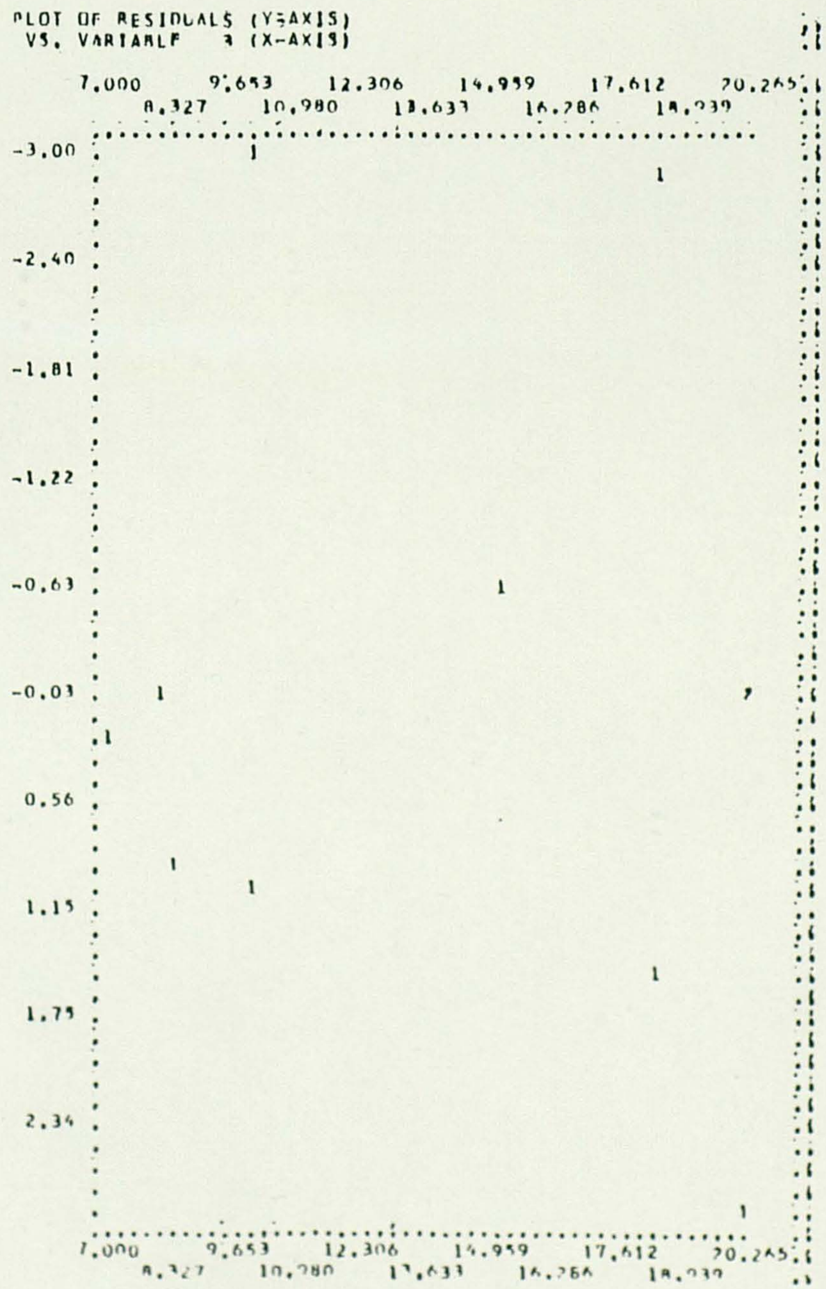
UMMARY TABLE

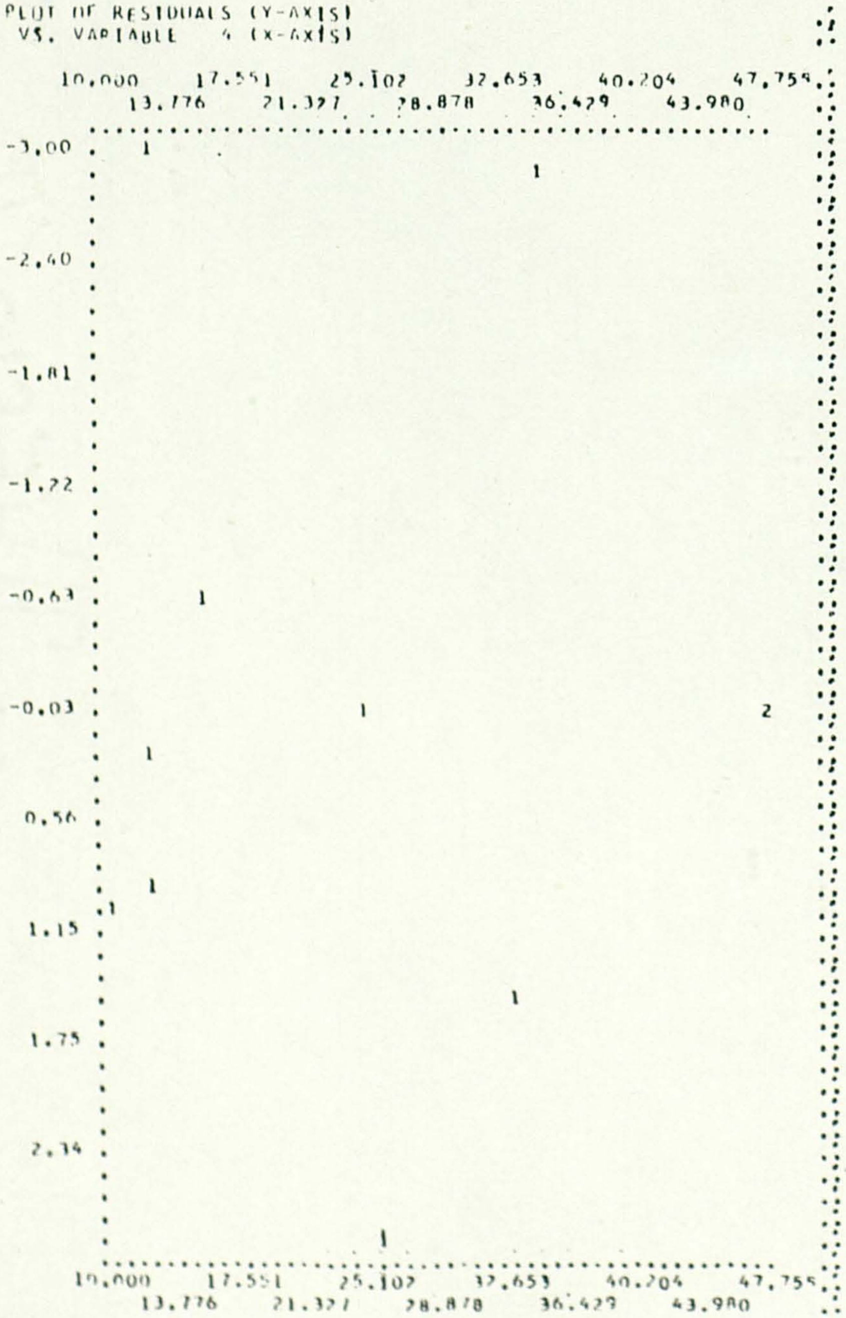
STEP NUMBER	VARIABLE ENTERED	REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	TOTWT 4		0.9070	0.8226	0.8226	41.7359	1
2	VERTCL 8		0.9220	0.8501	0.0275	1.4667	2
3	PITCH 5		0.9482	0.8991	0.0490	3.3990	3
10	9						

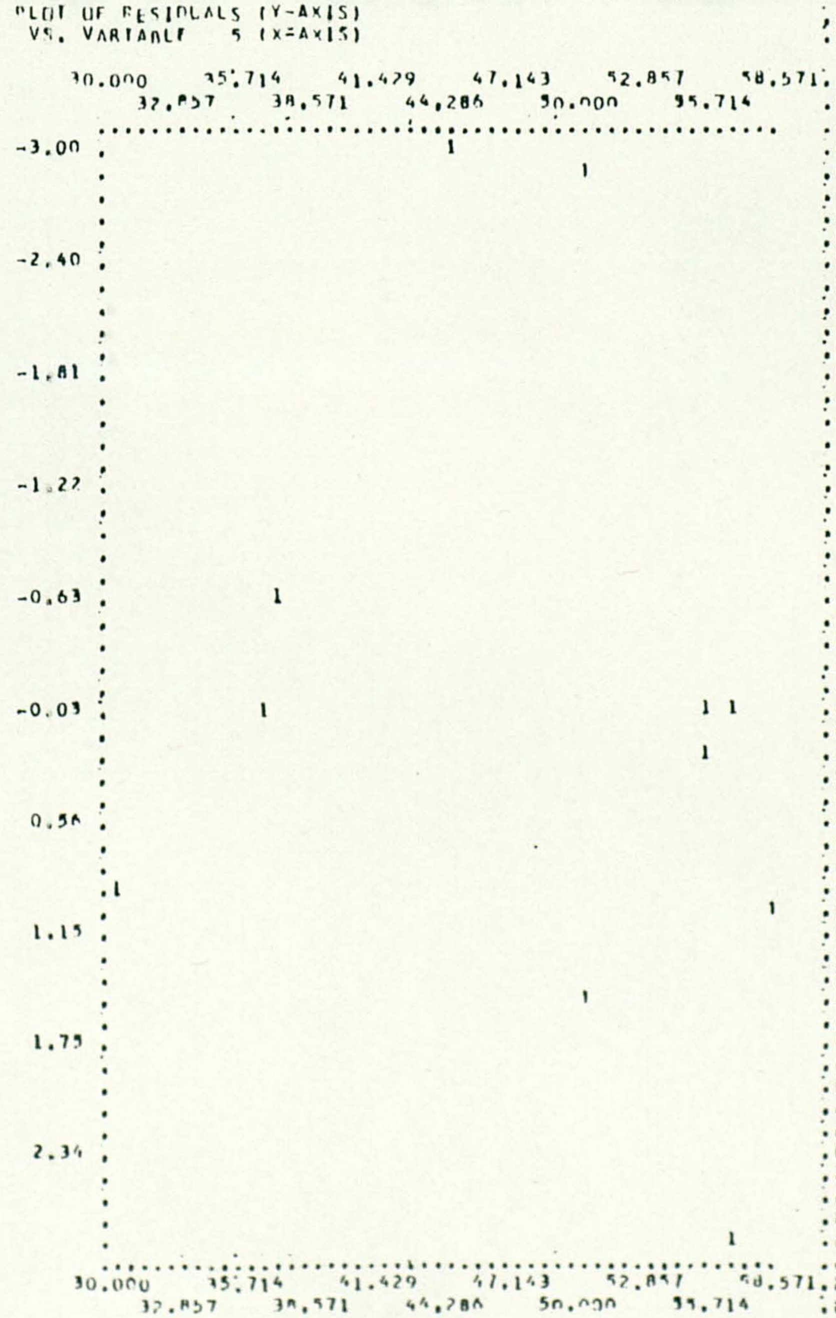
OF RESIDUALS

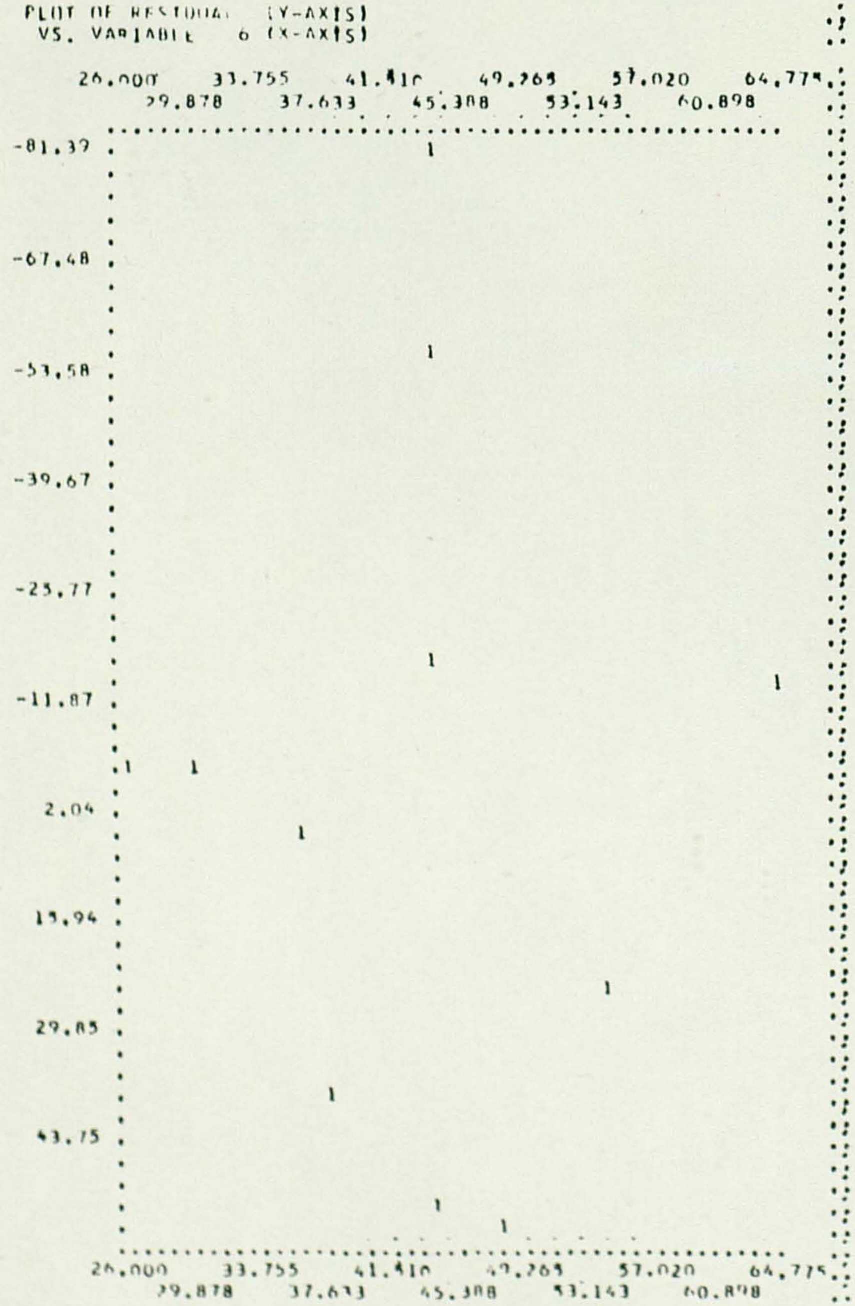
Y X(1)	Y COMPUTED	RESIDUAL	X(4)	X(8)	X(13)	X(12)	X(9)
386.0000	388.8257	-2.8257	33.9800	69.0000	0.0000	0.0000	96.0000
268.0000	266.9417	1.0583	10.0000	68.0000	0.0000	0.0000	76.0000
327.0000	325.5193	1.4807	37.6000	55.0000	0.0000	0.0000	84.0000
238.0000	237.1365	0.8635	12.4200	24.0000	0.0000	0.0000	30.0000
149.0000	149.5745	-0.5745	15.0000	0.0000	0.0000	0.0000	0.0000
327.0000	324.1841	2.8159	25.0000	66.0000	1.0000	0.0000	96.0000
238.0000	240.9980	-2.9980	17.5000	60.0000	1.0000	0.0000	80.0000
149.0000	148.8162	0.1838	12.0000	84.0000	1.0000	0.0000	56.0000
476.0000	475.9878	0.0122	47.0000	60.0000	0.0000	1.0000	96.0000
595.0000	595.0110	-0.0110	47.0000	96.0000	0.0000	1.0000	96.0000
357.0000	356.9995	0.0005	24.0000	75.0000	0.0000	0.0000	86.0000

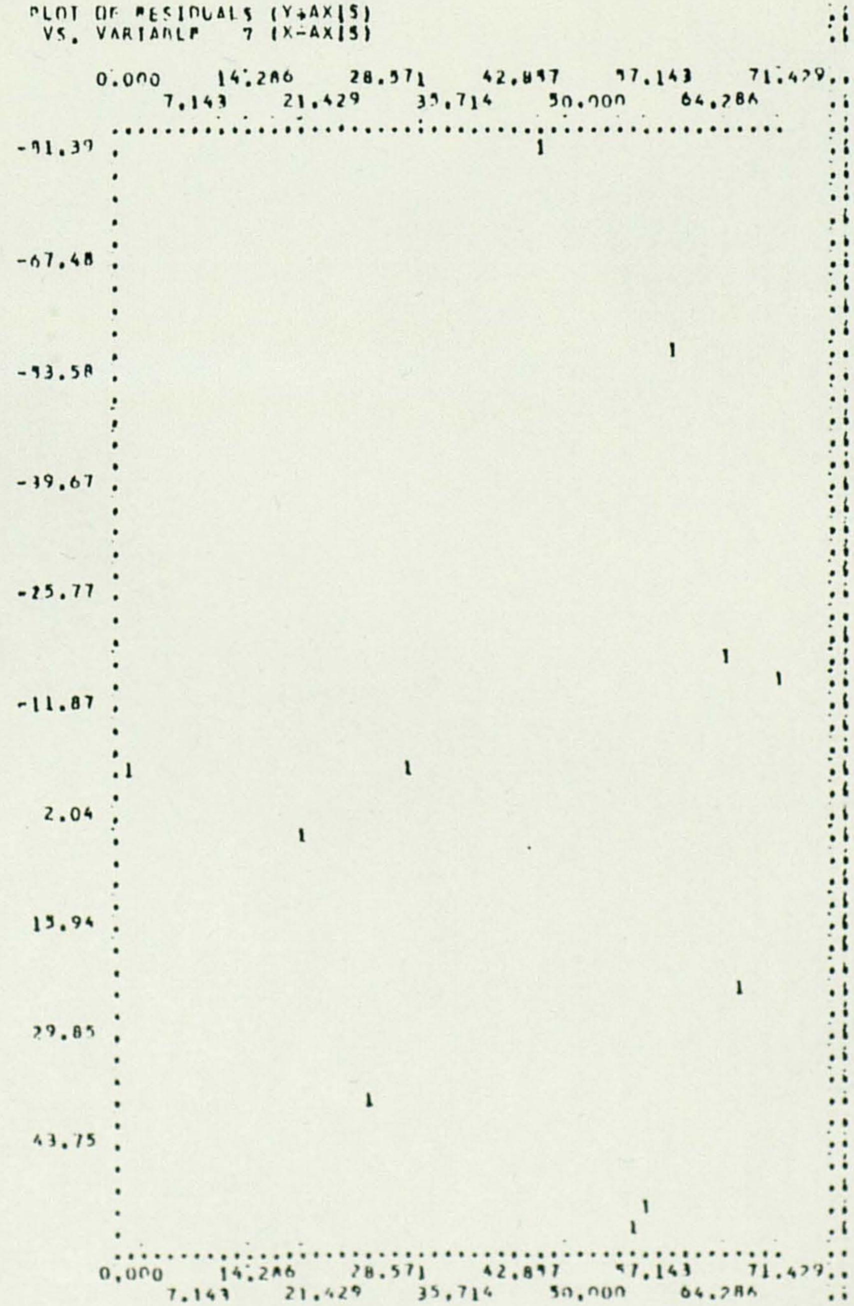

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)
3.000 3.612 4.224 4.837 5.449 6.061
3.306 3.918 4.531 5.143 5.755
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

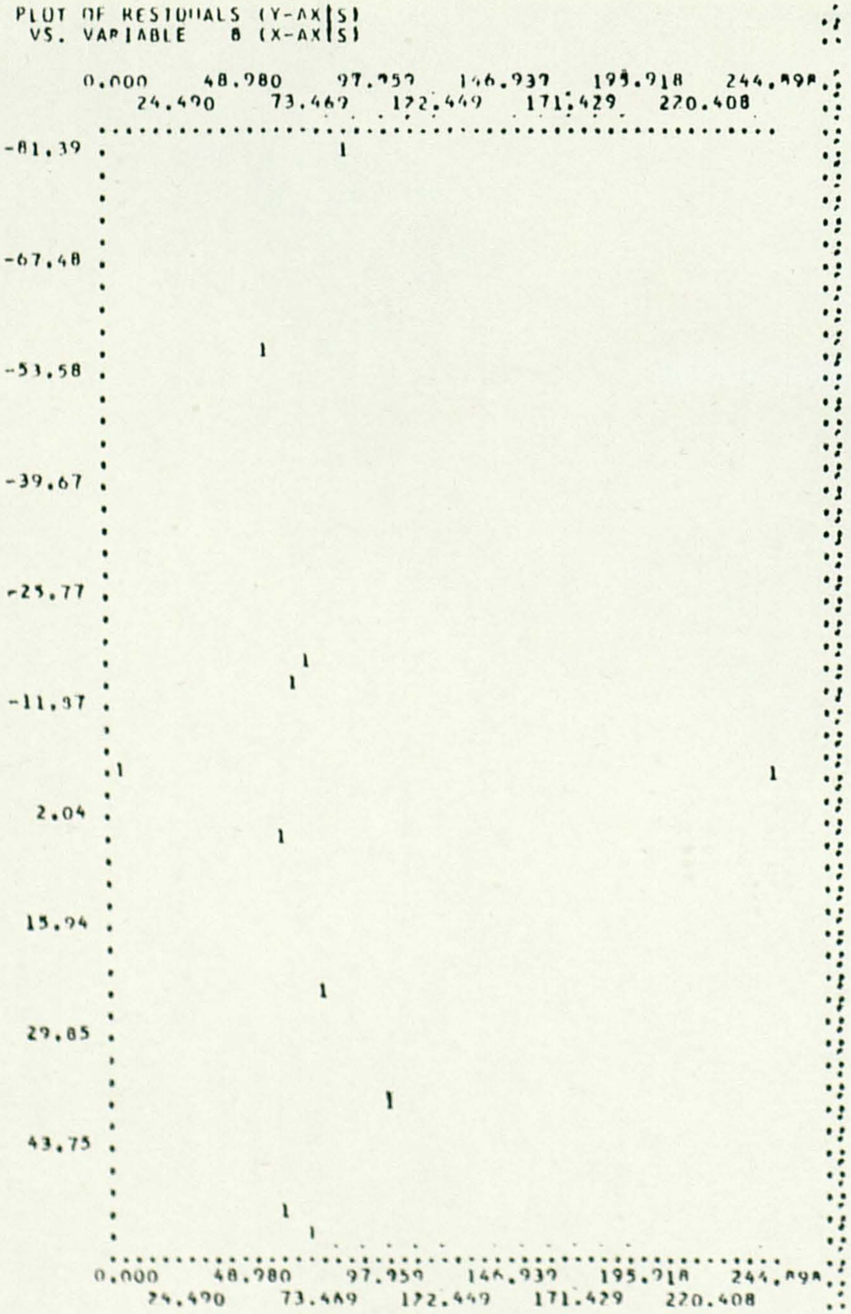

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)
7.000 9.653 12.306 14.959 17.612 20.265
8.327 10.980 13.633 16.286 18.939
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

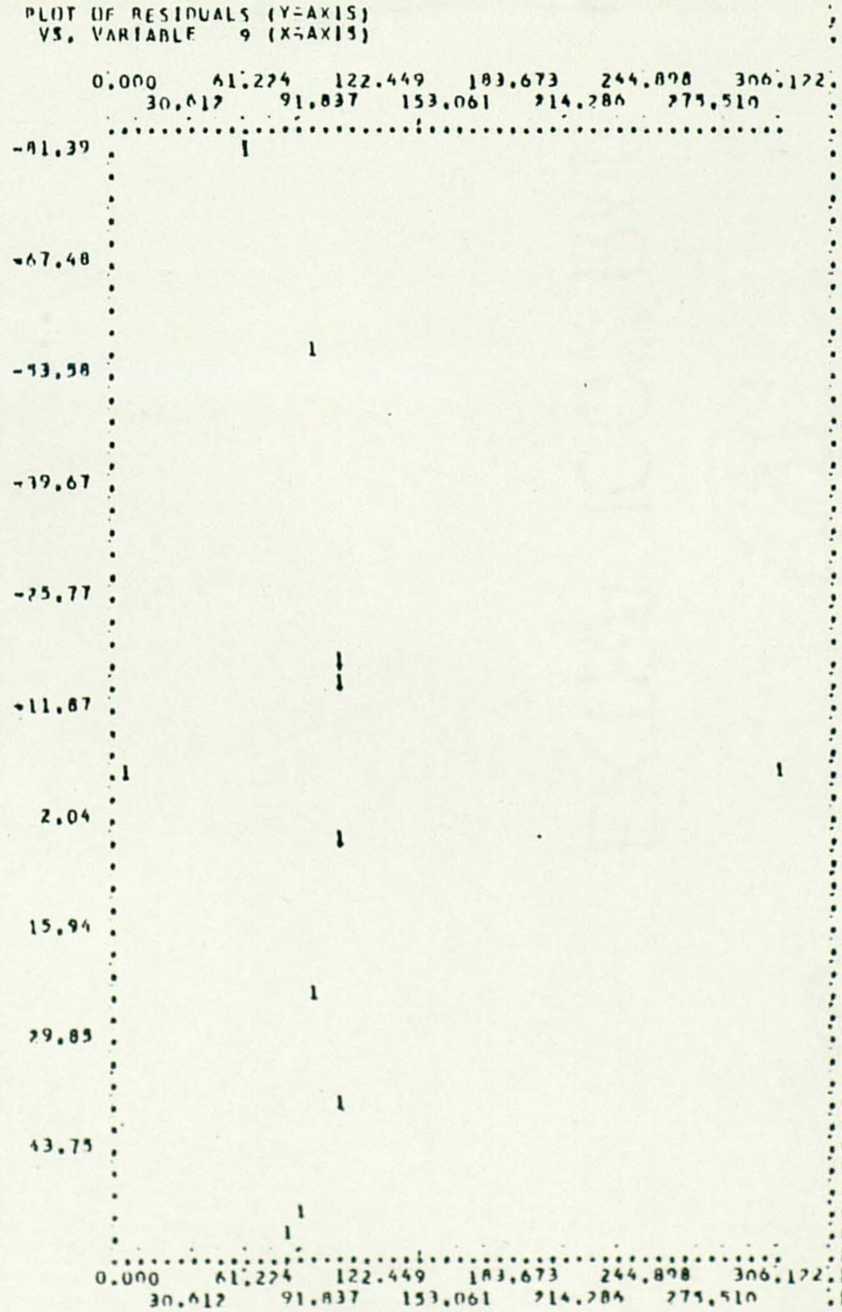

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)
10.000 17.551 25.102 32.653 40.204 47.755
13.776 21.327 28.878 36.429 43.980
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

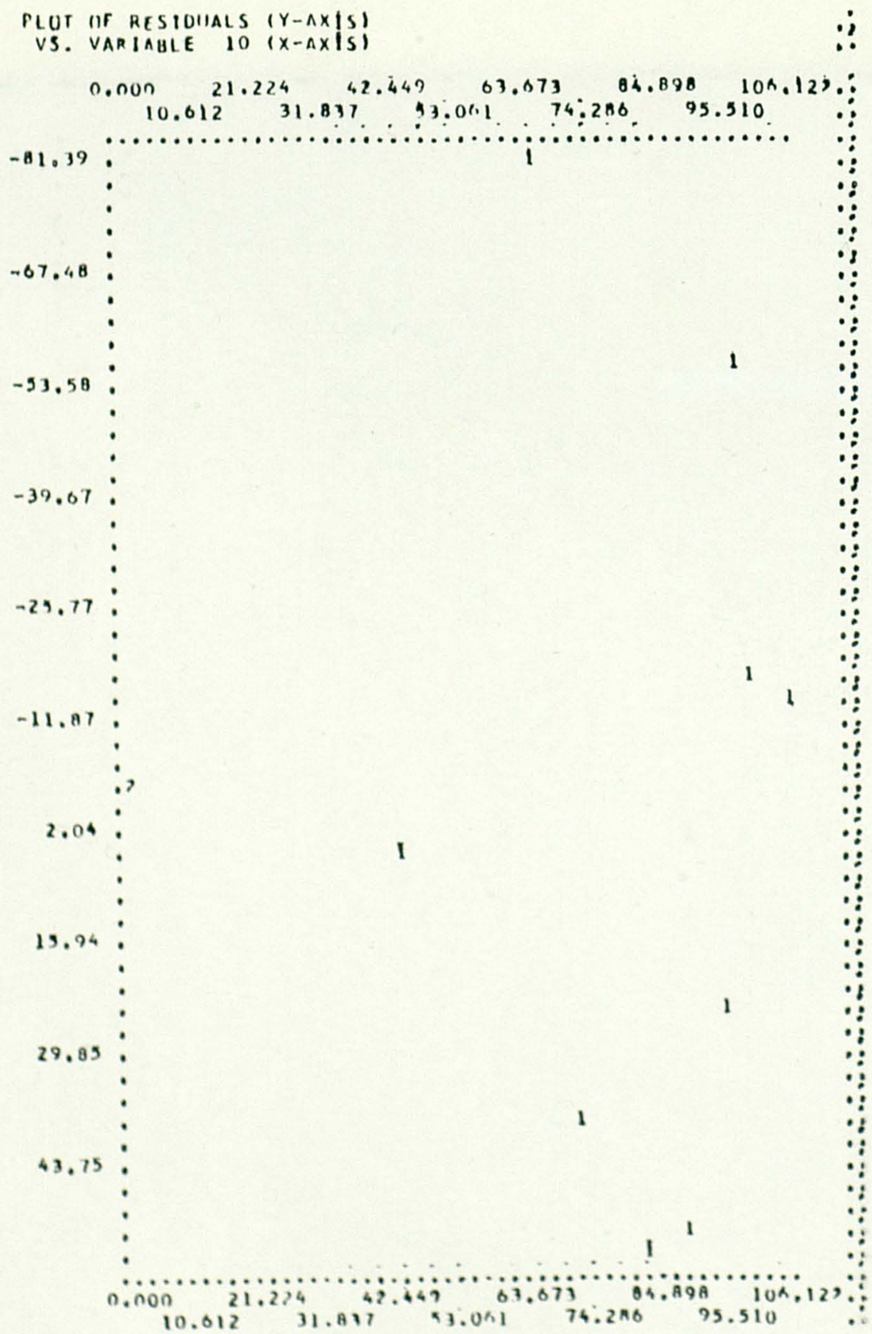

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)
30.000 35.714 41.429 47.143 52.857 58.571
32.857 38.571 44.286 50.000 55.714
-3.00
-2.40
-1.81
-1.22
-0.63
-0.03
0.56
1.15
1.75
2.34

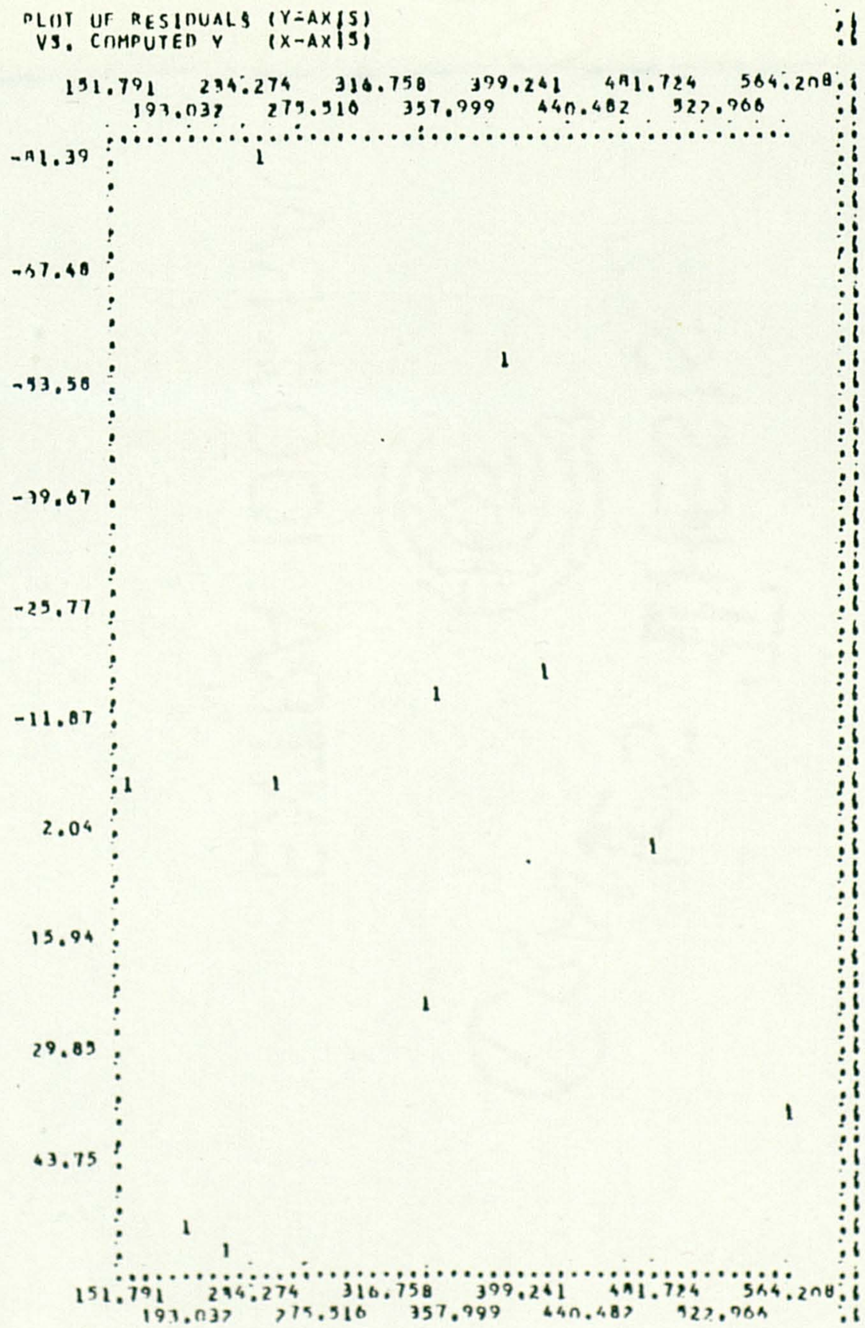

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 6 (X-AXIS)
26.000 33.755 41.510 49.265 57.020 64.775
29.878 37.633 45.388 53.143 60.898
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 7 (X-AXIS)
0.000 14.286 28.571 42.857 57.143 71.429
7.143 21.429 35.714 50.000 64.286
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 8 (X-AXIS)
0.000 48.980 97.959 146.939 195.918 244.898
24.490 73.469 122.449 171.429 220.408
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 9 (X-AXIS)
0.000 61.224 122.449 183.673 244.898 306.122
30.612 91.837 153.061 214.286 275.510
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 10 (X-AXIS)
0.000 21.224 42.449 63.673 84.898 106.122
10.612 31.837 53.061 74.286 95.510
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75


PLOT OF RESIDUALS (Y-AXIS)
VS. COMPUTED Y (X-AXIS)
151.791 234.274 316.758 399.241 481.724 564.208
193.032 275.516 357.999 440.482 522.966
-81.39
-67.48
-53.58
-39.67
-25.77
-11.87
2.04
15.94
29.85
43.75

FOOTNOTES

[1]Naval Training Equipment Center, "Procedures for Cost Estimating," Director of Engineering Memorandum 3910.1, Orlando, Florida, September 1974.

[2]Naval Training Equipment Center, "Functional Statement, Functional Description, Mini-Military Characteristics, and Detail Military Characteristics; instructions and responsibility for," Instruction 3910.4A, Orlando, Florida, February 1977.

[3]Naval Training Equipment Center, "Procedures for Cost Estimating," Director of Engineering Memorandum 3910.1, Orlando, Florida, September 1974.

[4]Naval Training Equipment Center, "Procedures for Cost Estimating," Director of Engineering Memorandum 3910.1, Orlando, Florida, September 1974.

[5]Naval Training Equipment Center, "Information Concerning Training Device Work Breakdown Structure (WBS)," Project Engineering Guide ED-PEG-A039, Orlando, Florida, March 1976. (Typewritten.)

[6]Naval Training Equipment Center, "Specification for AH-1Q (COBRA) Helicopter Operational Flight Trainer/ Weapons System and Simulator, Device 2B33," Task 3862, Orlando, Florida, 1974. (Mimeographed.)

[7]W. J. Dixon, ed., BMD Biomedical Computer Programs, 3rd ed. (Berkeley: University of California Press, 1973).

[8]Consultation and discussion with Dr. Robert D. Doering, on research report using PERT/Cost Technique, Florida Technological University, Orlando, Florida, November 1977.

[9]Consultation on Visual System Cost Estimating with Robert G. Palmer, Naval Training Equipment Center, Orlando, Florida, October 1977.

[10]Training Analysis and Evaluation Group, "Acquisition Cost Estimating Using Simulation," Orlando, Florida, September 1975. (Mimeographed.)

[11]Naval Training Equipment Center, "Average Industry Rates for Cost and Lead Time," Director of Procurement Services Memorandum, Orlando, Florida, March 1976.

[12]Interviews with selected systems engineers responsible for estimating on trainers, Naval Training Equipment Center, Orlando, Florida, October 1977.

[13]Naval Training Equipment Center, "Average Industry Rates for Cost and Lead Time," Director of Procurement Services Memorandum, Orlando, Florida, March 1976.

[14]Naval Training Equipment Center, "Average Industry Rates for Cost and Lead Time," Director of Procurement Services Memorandum, Orlando, Florida, March 1976.

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