LIBRARY	PROGRAM	PRESENT	CHANGE				
STATISTIC	<u>es</u>						
A & B	09100-70801 (Prog. Step, pp 1)	25 - X Code 30	25 - X Code 36				
A & B	09100-70802 (UI 1st entry point)	After last entry: SET FLAG before pressing CONTINUE	$f_i$ Y, $X_i + X$				
A & B	09100-70808 (Title)	$(E_i \neq E_i)$	$(E_i \neq E_j)$				
A & B	09100-70811 (Prog. Steps, pp 2)	$\begin{array}{ccc} \text{Step} & \text{Expression} \\ \textbf{4-7} & \ln X_i - \frac{\ln X_i}{N} & \cdot \\ & N & \end{array}$	Step Expression $(\ln x)^2 - (\ln x)^2$				
A & B	09100-70811 (Prog. Step pp 3)	Step Expression 6-1 $(\ln X_i - \frac{\ln X_i}{N})$	Step Expression 6-1 (ln x ln y)				
		$(\ln Y_i - \ln Y_i N)$	(lnx) (ln y) N				
A & B	09100-70811 (Prog. Step, pp 2)	$\begin{array}{ccc} \text{Step} & \text{Expression} \\ \text{5-3} & & \ln Y_i - \frac{\ln Y_i}{N} \end{array} 2$	Step Expression $5-3  (\ln y)^2 - (\ln y)^2$				

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# HP Computer Museum www.hpmuseum.net

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### September 1, 1969

#### 9100B STATISTICS PROGRAM LISTING

#### 70801 - MEAN AND STANDARD DEVIATION

Calculates the mean and standard deviation of n data points.



#### 70802 - STANDARD DEVIATION AND MEAN OF GROUPED DATA

Calculates the mean and standard deviation of data points of certain frequencies.

#### 70803 - LINEAR REGRESSION

Calculates the best fit of a set of data points to the line y = ax + b, i.e., the program computes the estimates â and b. It also gives the correlation coefficient r.

#### 70804 - NORMAL PROBABILITY INTEGRAL

Evaluates the integral of the normal density function.

70805 -  $\chi^2$  - CHI SQUARE DISTRIBUTION Calculates the integral of the Chi Square distribution from 0 up to a value of  $\chi^2$  for a given number of degrees of freedom.

# 70806 - $\chi^2$ - CHI SQUARE EVALUATION EXPECTED VALUES EQUAL (E $_i$ = E) Chi square calculation where the expected value of each observation is equal.

### 70808 - $\chi^2$ - CHI SQUARE EVALUATION EXPECTED VALUES UNEQUAL ( $E_i \neq E_j$ ) Chi square calculation where the expected values of the observations are not necessarily equal.

#### 70811 - LEAST SQUARES FIT-POWER CURVE

Calculates coefficients fitting data points  $(x_i, y_i)$  to an equation of the form:  $y = ax^b$ 

#### 70812 - LEAST SQUARES FIT-EXPONENTIAL

Calculates coefficients fitting data points  $(x_i, y_i)$  to an equation of the form:  $y = ae^{bx}$ 

#### 70813 - POISSON DENSITY

Calculates the various summations associated with the Poisson density to give a probability based on an input parameter and summation endpoints.

#### 70816 - RANDOM NUMBER GENERATOR

Random numbers (RN) in the range  $0 \le RN \le 1$  are calculated; more than 10,000 random numbers may be generated before any previous value is repeated.

#### 70904 - NORMAL (GAUSSIAN) CURVE PLOT

Given mean (M) and variance  $\sigma^2$ , this program generates a normal curve given by

$$y = \frac{1}{\sigma\sqrt{2\pi}} \quad e^{\frac{-(X - M)^2}{2\sigma^2}}$$

This program can be used with Program 70905, Histogram Generation.

### 70907 - ONE WAY ANALYSIS OF VARIANCE

This program separates the total variance in a table of data into that due to chance and that due to differences between the population means underlying each column of sample data.

#### 9100B ONLY

#### 70901 - MULTIPLE LINEAR REGRESSIONS

Given a set of data points (Xi, Yi, Zi), this program determines the coefficients of the linear equation

$$Z = a_0 + a_1 X + a_2 Y$$

- 70902 WEIBULL DISTRIBUTION PARAMETER CALCULATION FOR FAILURE DATA Calculates the parameters for the Weibull distribution and thus estimates of times to failure percentages may be made.
- 70903 NON-LINEAR REGRESSION LEAST SQUARES PARABOLA Calculates coefficients fitting data points (x<sub>i</sub>, y<sub>i</sub>) to an equation of the form:

$$y = a_0 + a_1 x + a_2 x^2$$

#### 70905 - HISTOGRAM GENERATION WITH PLOT

This program generates and plots a histogram of ten windows given a set of positive numbers. The mean M and variance  $\sigma^2$  of the data set are computed and stored for use by Program 70904, NORMAL CURVE PLOT.

#### 70906 - HISTOGRAM GENERATION

This program generates a histogram table of ten windows given a data set of positive numbers. In addition it determines the mean M and the variance  $\sigma^2$  of the data set.

#### 70908 - F DISTRIBUTION

This program evaluates the F distribution density function for given values of F,  $V_1$ , and  $V_2$ .

#### 70909 - TWO WAY ANALYSIS OF VARIANCE (m X 4)

This program analyses the total statistical variance in a table of data by separating the total variance into two parts, the variance among rows, and the variance between columns. These variances are then compared to the variance due to random influence.

#### 70910 - TWO WAY ANALYSIS OF VARIANCE WITH REPLICATES

This program analyses the total statistical variance of a table of data by separating the total variance into three parts; the variance among rows, the variance between columns, and the variance due to interaction.



#### MEAN AND STANDARD DEVIATION

This program calculates the mean,  $\overline{X}$ , and standard deviation, S, of a set of data points by the equations

and 
$$\overline{X} = \frac{\sum_{j=1}^{n} X_{j}}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} (X_{j} - \overline{X})^{2}}{n-1}}$$

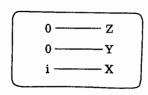
Reference: Introduction to the Theory of Statistics by Mood and Graybill

McGraw - Hill 1963

PRESS: GO TO (0) (0) or END

PRESS: CONTINUE

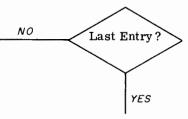
DISPLAY



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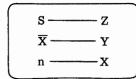
ENTER DATA: X<sub>i</sub> → X

PRESS: CONTINUE



PRESS: SET FLAG PRESS: CONTINUE

DISPLAY



S = Standard deviation

 $\overline{X}$  = Mean

n = Number of data points

${ t SAMPLE}$	ATA
---------------	-----

5.036

5.085

4.991

4.935

S = .0493

n = 10

4.999 5.031

 $\overline{\mathbf{X}} = 5.0145$ 

5.064

4.942

5.051

5.011

#### SAMPLE DATA

4

5

6

 $\overline{X} = 4.6667$ 

7

n = 6

S = 1.7512

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#### MEAN AND STANDARD DEVIATION OF GROUPED DATA

This program calculates the mean,  $\bar{X}$ , and standard deviation, S, of a set of data points  $X_1$ ,  $X_2$ ,  $\cdots$ ,  $X_K$  with frequencies  $f_1$ ,  $f_2$ ,  $\cdots$ ,  $f_K$  respectively. The equations used are

$$\overline{X} = \frac{\sum_{i=1}^{K} f_i X_i}{\sum_{i=1}^{K} f_i}$$

$$S = \sqrt{\frac{\sum_{i=1}^{K} f_i (X_i - \overline{X})^2}{\sum_{i=1}^{K} f_i - I}}$$

Reference: Introduction to the Theory of Statistics

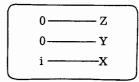
by Mood and Graybill

McGraw - Hill 1963

PRESS: GO TO (0) (0) [or END]

PRESS: CONTINUE

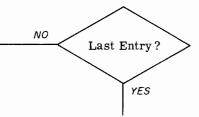
**→** DISPLAY



(i indicates pair of points to be entered)

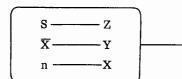
enter data:  $f_i \rightarrow Y$ ,  $X_i \rightarrow X$ 

PRESS: CONTINUE



PRESS: SET FLAG
PRESS: CONTINUE

DISPLAY



S = Standard Deviation

 $\overline{X}$  = Mean

n = Number of Data Points

#### SAMPLE DATA

$x_i$	$^{\mathbf{f}}\mathbf{i}$	
1	3	
2	3	S = 1.433
3	1	$\overline{X} = 2.5$
4	2	n = 10
5	1	

#### SAMPLE DATA

$\mathbf{x}_{\mathbf{i}}$	$^{\mathrm{f}}\mathbf{i}$
41	3
38	5
37	2
<b>3</b> 9	18
40	22

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#### LINEAR REGRESSION AND CORRELATION COEFFICIENT

This program calculates the equation of the straight line of best fit of a set of data points. The best fit is determined by minimizing the sum of the squares of the deviations of the data points from the line.

The program calculates m and b for the equation

$$Y = mX + b$$
.

The program also calculates a correlation coefficient r, an indication of goodness of fit. Note  $-1 \le r \le 1$  where the sign corresponds to the slope m. If r = 0 there is no correlation, and if  $r = \pm 1$  there is perfect correlation or a perfect fit.

The defining equations are

$$m = \frac{\sum_{j=1}^{n} (X_{j} - \overline{X})(Y_{j} - \overline{Y})}{\sum_{j=1}^{n} (X_{j} - \overline{X})^{2}}$$

$$b = \overline{Y} - m\overline{X}$$

where 
$$\overline{Y} = \frac{\sum_{j=1}^{n} Y_{j}}{n}$$
 and  $\overline{X} = \frac{\sum_{j=1}^{n} X_{j}}{n}$ 

$$r = \frac{\sum_{i=1}^{n} (X_{i} - \overline{X})(Y_{i} - \overline{Y})}{\sqrt{\sum_{i=1}^{n} (X_{i} - \overline{X})^{2} \sum (Y_{i} - \overline{Y})^{2}}}^{2}$$

Reference: Mathematical Statistics

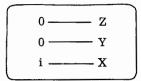
by John E. Freund

Prentice - Hall 1962

PRESS: GO TO (0) (0) or END

PRESS: CONTINUE

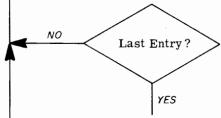
→ DISPLAY



(i indicates pair of points to be entered)

enter data:  $\mathbf{Y}_{\mathbf{i}}$   $\longrightarrow$   $\mathbf{Y}$ ,  $\mathbf{X}_{\mathbf{i}}$   $\longrightarrow$   $\mathbf{X}$ 

PRESS: CONTINUE



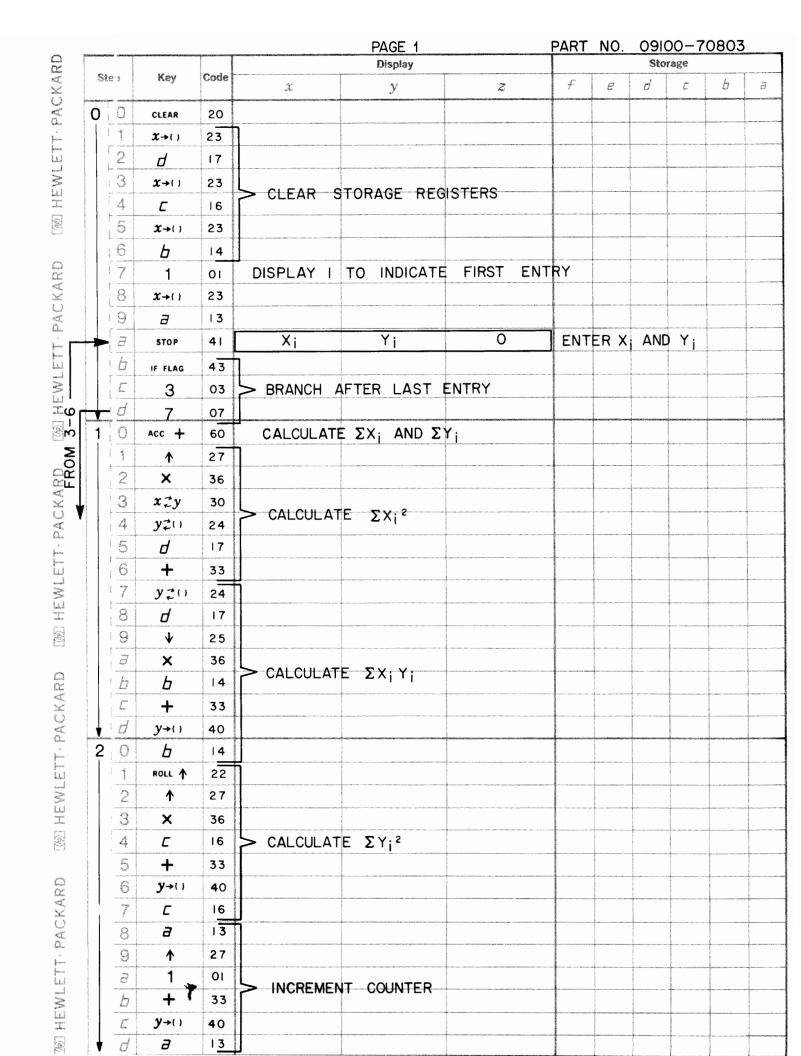
PRESS: SET FLAG
PRESS: CONTINUE

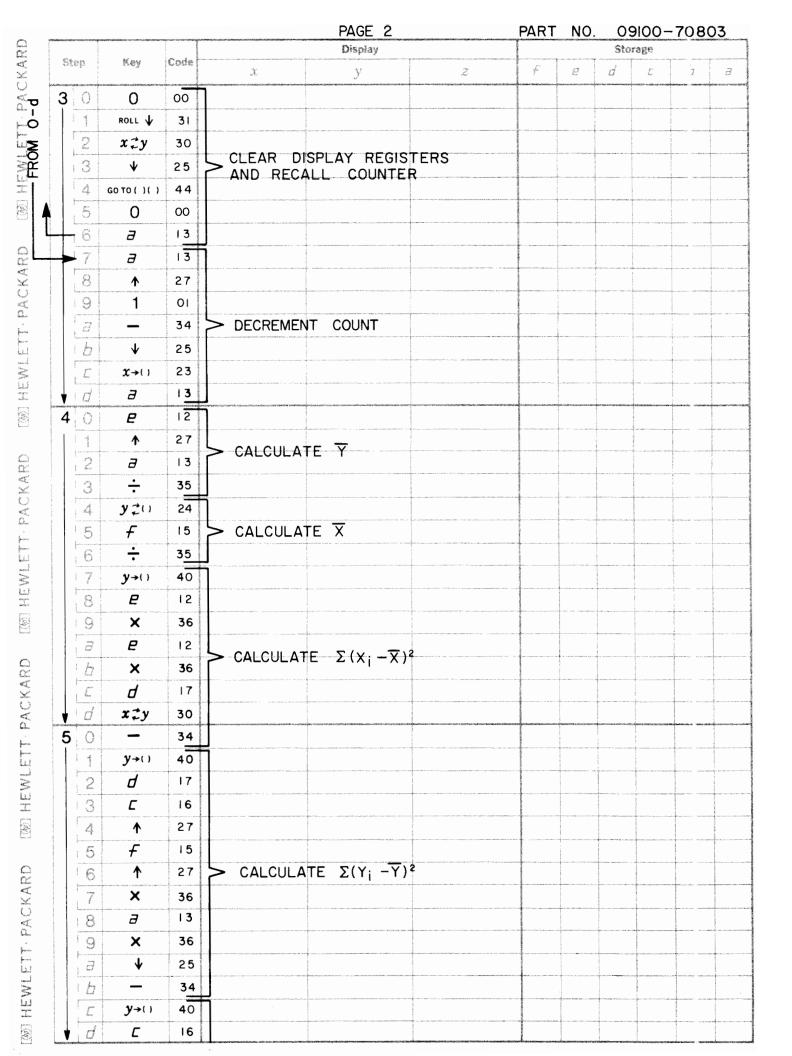
DISPLAY

r — Z
b — Y
m — X

X	Y	
26	92	
30	85	r =96
44	78	b = 121.04
50	81	m = -1.03
62	54	
68	51	Y = -1.03X + 121.04
74	40	

X	Y	
0	1	
1	3	r = .9
2	2	b = 1.2
3	4	m = .9
4	5	
		Y = .9X + 1.2







#### NORMAL PROBABILITY INTEGRAL

This program computes the integral of the standardized normal distribution

$$P(X) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{X} \bar{e}^{\frac{1}{2} Z^{2}} dZ$$

The following equations are used



$$P(X) = \frac{erf(\frac{X}{\sqrt{2}})}{2} + \frac{1}{2}$$

where

$$erf(X) = \frac{2}{\sqrt{\pi}} e^{-x^2} \sum_{n=0}^{\infty} \frac{2^n}{1 \cdot 3 \cdots (2n+1)} X^{2n+1}$$

Reference: Handbook of Mathematical Functions by Abramowitz and Stegan

National Bureau of Standards 1964

#### USER INSTRUCTIONS

#### EXAMPLES

ENTER PROGRAM (Starting Address is 0 - 0)

PRESS: GO TO (0) (0) or END

- PRESS: CONTINUE

DISTLAT

EFITER DATA: X --- \* X

PRESS: CONTINUE

DISPLAY

X = .3

P(X) = .618

X = -.3

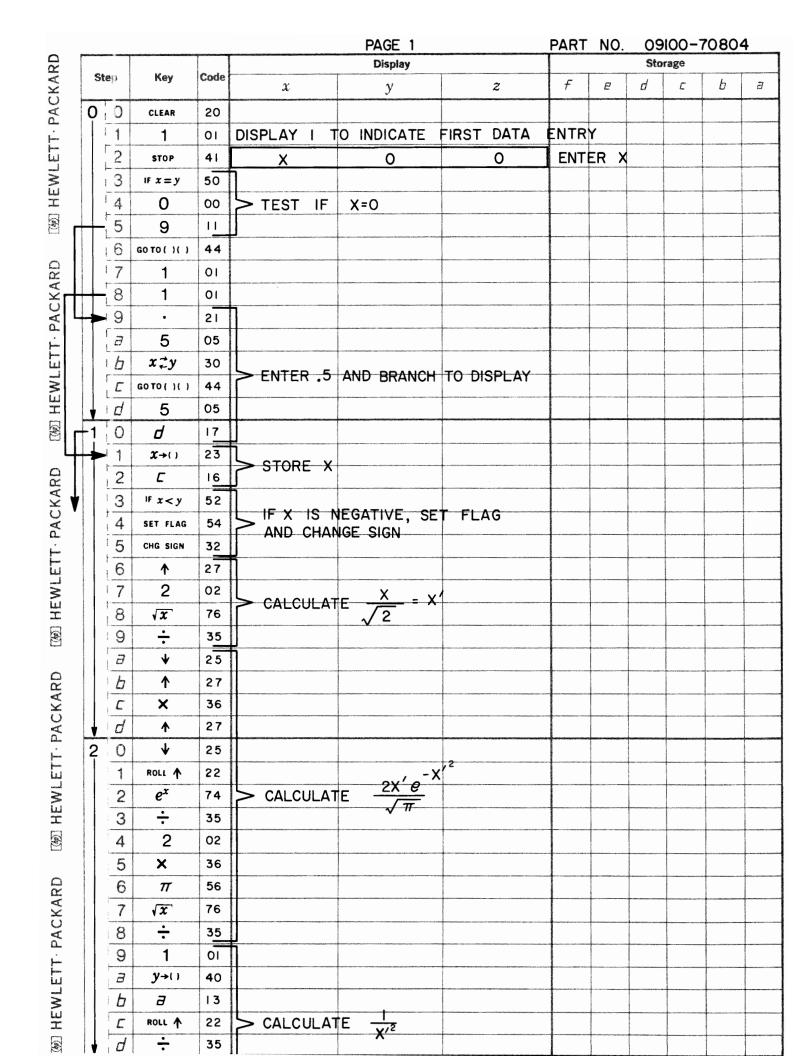
P(X) = .382

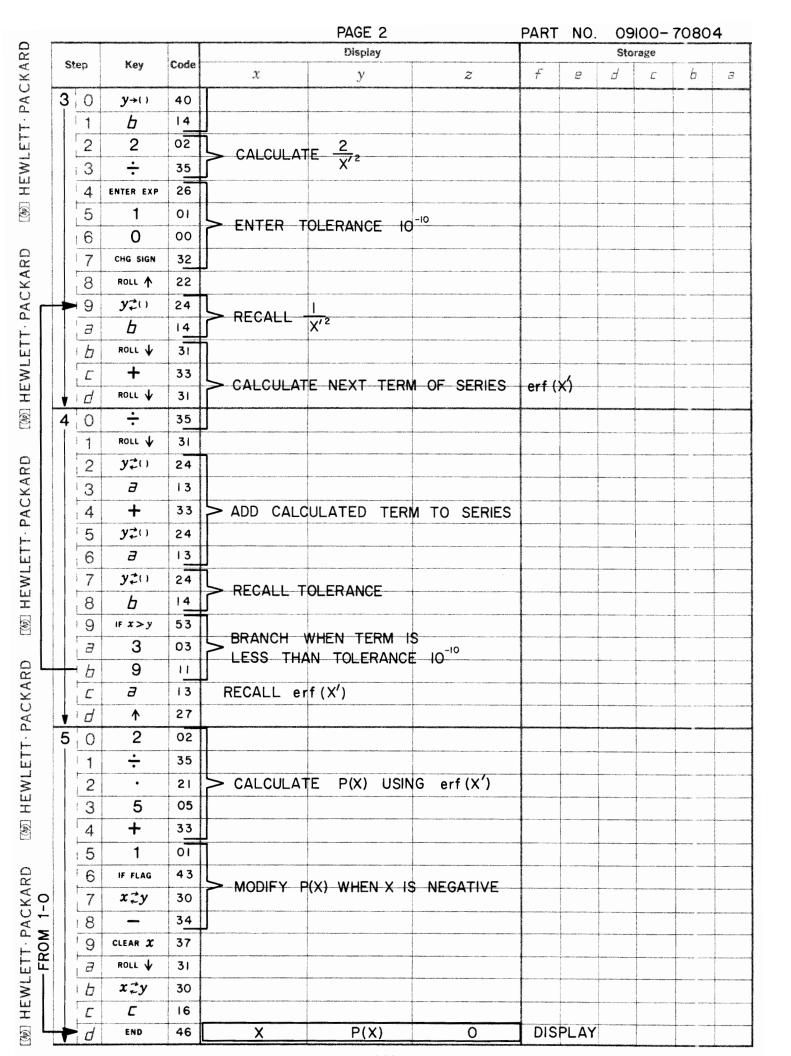
 $\mathbf{X} = \mathbf{0}$ 

P(X) = .5

 $\Sigma = 3$ 

 $P(\Xi) = .999$ 







This program evaluates the Chi Square Distribution Integral for a given value of  $\chi^2$  and  $\nu$  degrees of freedom; i.e., the program evaluates

$$P(\chi^{2}, \nu) = \frac{1}{2^{\frac{1}{2}} \prod_{i=1}^{2} \prod_{j=1}^{2} \int_{0}^{\chi^{2}} T^{\frac{1}{2} - 1} e^{-\frac{1}{2}} dT$$
  $0 \le \chi^{2}$ 

The series approximation used to evaluate the integral is

$$P(\chi^{2},\nu) = (\frac{1}{2}\chi^{2})^{\frac{1}{2}} \frac{e^{-\frac{\chi^{2}}{2}}}{\Gamma(\frac{\nu+2}{2})} \left\{ 1 + \sum_{r=1}^{\infty} \frac{\chi^{2r}}{(\nu+2)(\nu+4)\cdots(\nu+2r)} \right\}$$

Reference: Handbook of Mathematical Functions by Abramowitz and Stegan

> National Bureau of Standards 1964

PRESS: GO TO (0) (0) [or END]

→ PRESS: CONTINUE

ENTER DATA:  $\chi^2 \longrightarrow Y$ ,  $\nu \longrightarrow X$ 

PRESS: CONTINUE

DISPLAY

$$\begin{bmatrix}
P(X^2, \nu) & & Z \\
\chi^2 & & Y \\
\nu & & & X
\end{bmatrix}$$

P(7.88, 1) = .995

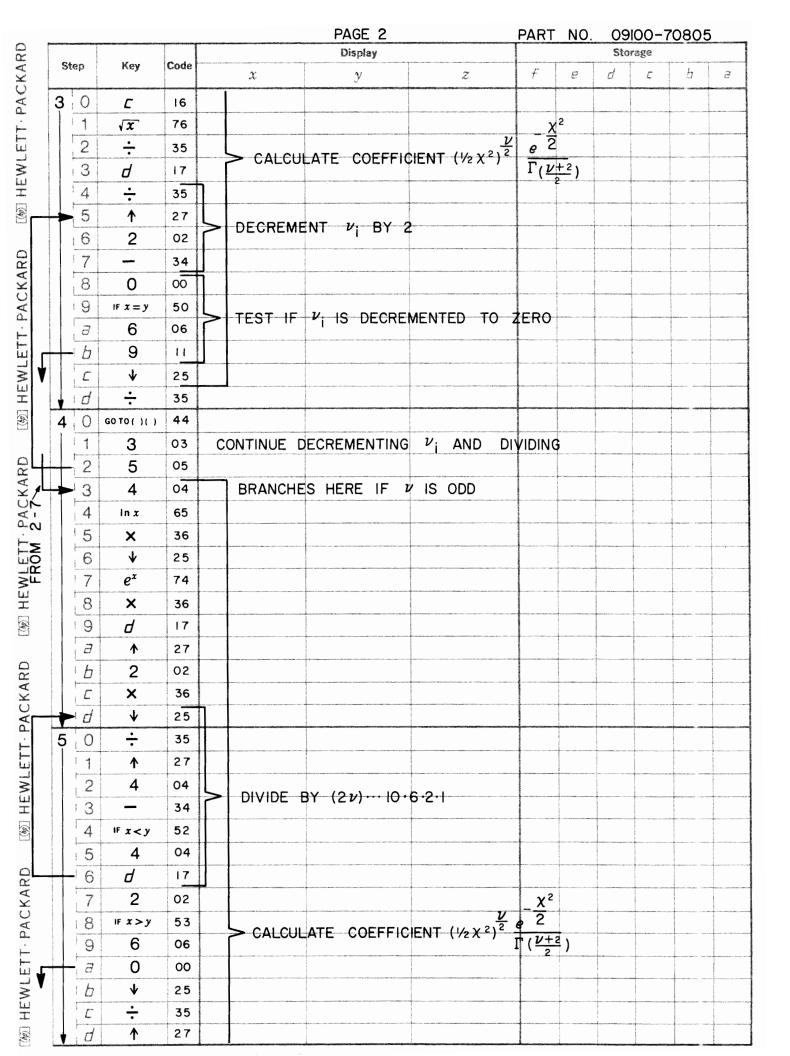
P(10.6, 2) = .995

P(12.8, 17) = .251

GENERAL FORM

 $P(X^2, \nu)$ 

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## $\chi^2$ CHI SQUARE EVALUATION EXPECTED VALUES EQUAL (E<sub>i</sub> = E)

PART NO. 09100-70806

This program calculates the value of  $\chi^2$  by the equation

$$\chi^2 = \sum_{j=1}^{n} \frac{(O_j - E_j)^2}{E_j}$$

 $\quad \text{where} \quad$ 

$$O_i$$
 — observed frequency  
 $E$  — expected frequency of  $O_i$  is  $E = \frac{\sum_{i=1}^{n} O_i}{n}$ 

Reference: Mathematical Statistics by John E. Freund

Prentice - Hall 1962

ENTER PROGRAM (Starting Address is 0 - 0)

PRESS: GO TO (0) (0) [or END]

PRESS: CONTINUE

O — Z

O — Y

i — X

(i indicates point to be entered)

ENTER DATA: Oi — X

PRESS: CONTINUE

NO

Last Entry?

PRESS: SET FLAG

PRESS: CONTINUE

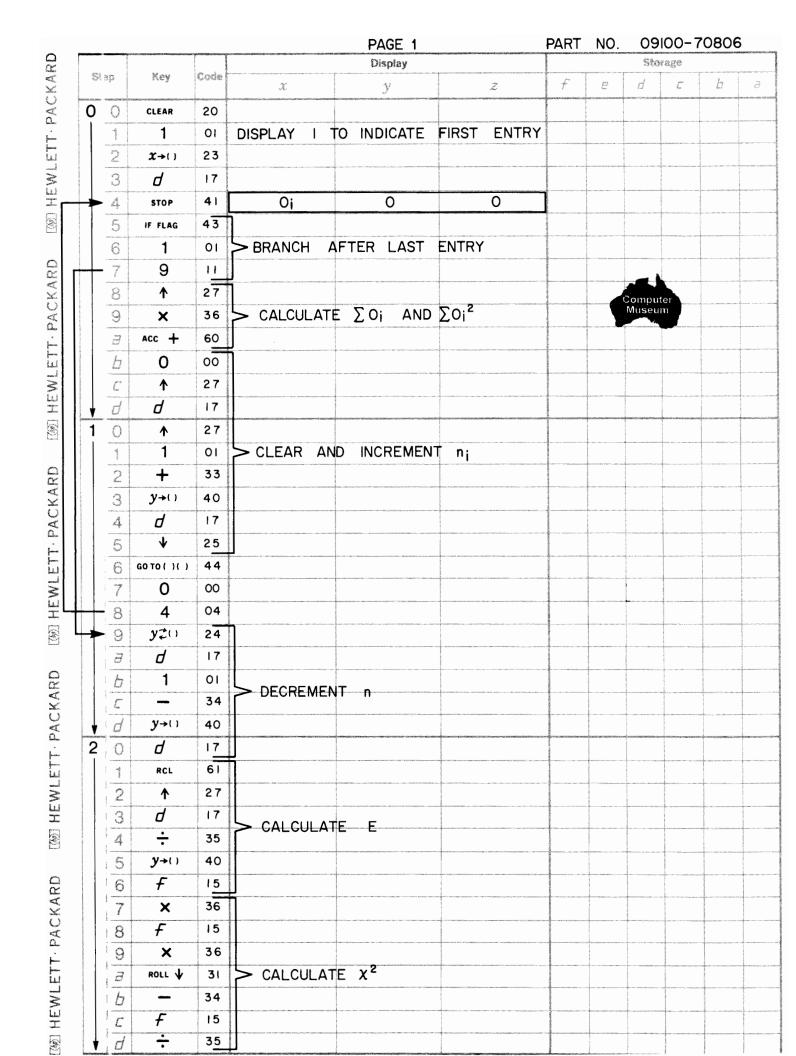
DISPLAY

E — Z

X<sup>2</sup> — Y

The table shows the observed and expected frequencies in tossing a die 120 times. Calculate  $\chi^2$  for testing if the die is fair.

$$E = 20$$
  
 $X^2 = 5.0$   
 $n = 6$ 



1921 HEWLETT PACKARD CAN HEWLETT PACKARD WENLETT PACKARD THE WLETT PACKARD CA TEVLET PACKARD



## $\chi^2$ CHI SQUARE EVALUATION EXPECTED VALUES UNEQUAL (E<sub>i</sub> $\neq$ E<sub>j</sub>)

June 1969 PART NO. 09100-70808

This program calculates the value of  $\boldsymbol{X}^{\,2}$  by the equation

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

where  $O_i$  — observed frequency

E; - expected frequency of Oi

Reference: Mathematical Statistics

by John E. Freund

Prentice - Hall 1962

▲ Denotes Revision

PRESS: GO TO (0) (0) [or END]

PRESS: CONTINUE

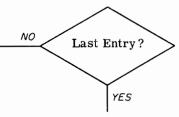
**→** DISPLAY

0 ------ z
0 ------- y
i ------- X

(i indicates points to be entered)

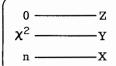
enter data:  $O_i \longrightarrow Y$ ,  $E_i \longrightarrow X$ 

PRESS: CONTINUE



PRESS: SET FLAG
PRESS: CONTINUE

DISPLAY



The table shows the observed and expected frequencies of some numbers. Calculate  $\mathbf{X}^2$ .

i	1	2	3	4	5	6
$O_i - rac{Observed}{Frequency}$	8	50	47	56	5	14
$\mathrm{E_{i}}$ - $rac{\mathrm{Expected}}{\mathrm{Frequency}}$	9.6	46.75	51.85	54.4	8.25	9.15

$$\chi^2 = 4.844$$
  
n = 6

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#### LEAST SQUARES FIT - POWER CURVE

PART NO. 09100-70811

This program computes the least squares fit and correlation coefficient of N pairs of data points for a power curve of the form:

 $Y = aX^b$ 

The equation is linearized into

$$lnY = blnX + lna$$

where

$$b = \frac{N\sum (\ln X \ln Y) - \sum \ln X \sum \ln Y}{N\sum (\ln X)^2 - (\sum \ln X)^2}$$

and

$$r = \frac{N \sum \ln x \ln y - (\sum \ln x)(\sum \ln y)}{\sqrt{\left[N \sum (\ln x)^2 - (\sum \ln x)^2\right] \left[N \sum (\ln y)^2 - (\sum \ln y)^2\right]}}$$

$$\ln a = \frac{\sum \ln Y}{N} - \frac{\sum \ln X}{N} \quad b$$

Note:

$$X_i > 0$$
 and  $Y_i > 0$ ,  $i = 1, \dots, N$ 

Reference: Statistical Theory and Methodology in Science and Engineering

by K.A. Brownlee

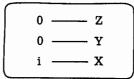
John Wiley and Sons 1965

ENTER PROGRAM (Starting Address is 0-0)

PRESS: GO TO (0) (0) or END

PRESS: CONTINUE

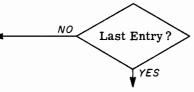
DISPLAY



(i indicates pair of points to be entered)

enter data:  $Y_i \rightarrow Y$ ,  $X_i \rightarrow X$ 

PRESS: CONTINUE



PRESS: SET FLAG
PRESS: CONTINUE

DISPLAY

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X	Y
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3.16	14. 55
10	9.26
31.6	5. 63
100	3.48
316	2.12
1000	1.7

$$r = -0.9964$$

$$b = -0.4022$$

$$a = 23.5871$$

$$Y = 23.5871X^{-.4022}$$

X	Y
1	3
2	4.2574
3	5.2248
4	6.0417
5	6, 7624

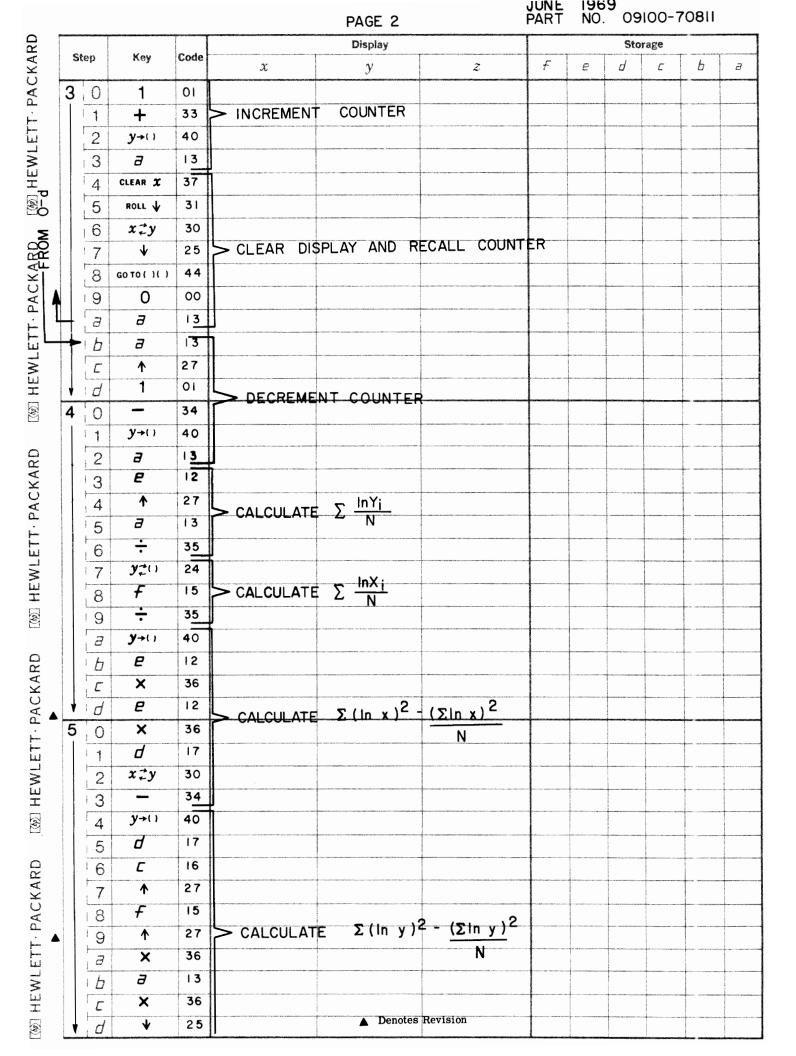
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$$b = .505$$

$$a = 3.000$$

$$Y = 3X^{\cdot 505}$$

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JUNE 1969 NO. 09100-70811 PAGE 3 PART MEWLETT PACKARD Display Storage Ster Code Key b  $\boldsymbol{\chi}$ d Ľ. 2 y z6 34 40 y→() 2 С ۱6 1-3 14 Ь 4 ↑ 27 5 F 15 27 3 M HEWLETT PACKARD 12 2 17 lny) -  $(\Sigma ln x)(\Sigma ln y)$ Σ(In x > CALCULATE 36 × 3 N 3 13 3 × 36 7 ₩ 25 5 34 17 Д J 个 27 0 25 1 [60] HEWLETT · PACKARD  $\sqrt{x}$ 76 2 > CALCULATE r 35 3 Ε 16 4 76  $\sqrt{x}$ 5 ÷ 35 17 Д 17 ROLL A 22 8 > CALCULATE b 30 xzy9 ÷ 3<u>5</u> 3 [162] HEWLETT PACKARD 24 y=() b 2 12 -2 12 J 8  $\overline{\mathsf{x}}$ 36 > CALCULATE In a 0 F 15 11  $x \stackrel{?}{\sim} y$ 30 2 34 3 12 2 4  $x \stackrel{\rightarrow}{=} y$ 30 5  $e^{x}$ 74 (4) HEWLETT PACKARD 6 7 END 46 b DISPLAY a r 8 9 Э 16 C d ▲ Denotes Revision



## PART NO. 09100-70812

#### LEAST SQUARES FIT - EXPONENTIAL

This program computes the least squares fit and a correlation coefficient of n pairs of data points for an exponential function of the form:

y = ae<sup>bx</sup>

The equation is linearized into

$$lny = lna + bx$$

or

$$Y = A + bx$$

Using a linear regression method,

$$b = \frac{n\sum xY - \sum x\sum Y}{n\sum x^2 - (\sum x)^2}$$

$$A = \frac{\sum Y - b \sum x}{n}$$

$$a = e^{A}$$

the correlation coefficient is given by

$$r = \frac{n \sum xY - \sum x \sum Y}{\sqrt{\left[n \sum x^2 - (\sum x)^2\right] \left[n \sum Y^2 - (\sum Y)^2\right]}}$$

Note: 
$$Y_i > 0$$
  $i = 1, \dots, n$ 

Reference: Statistical Theory and Methodology in Science and Engineering

by K.A. Brownlee

John Wiley and Sons 1965

### ENTER PROGRAM (Starting Address is 0-0)

PRESS: GO TO (0) (0) [or END]

PRESS: CONTINUE

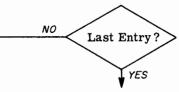
➤ DISPLAY

0 ---- Z 0 ---- Y i ---- X

(i indicates pair of points to be entered)

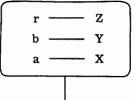
enter data:  $Y_i \longrightarrow Y$ ,  $X_i \longrightarrow X$ 

PRESS: CONTINUE



PRESS: SET FLAG
PRESS: CONTINUE

DISPLAY



GENERAL FORM:  $Y = ae^{bX}$ 

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		$Y = 3.103e^{503X}$

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#### POISSON DENSITY

PART NO. 09100-70813

The Poisson density function is defined by  $f(n; \lambda) = \frac{\lambda^n e^{-\lambda}}{n!}$ where  $\lambda$  may be estimated by

 $\boldsymbol{\hat{\lambda}}$  = the expected value of  $\boldsymbol{x}_i$  (n = 0, 1, 2, ...)

$$\sum_{n=0}^{\infty} \frac{\lambda^n e^{-\lambda}}{n!} = e^{-\lambda} \sum_{n=0}^{\infty} \frac{\lambda^n}{n!} = e^{-\lambda} e^{\lambda} = 1$$

The Poisson density function is a descrete density which is used to evaluate such things as component failure probabilities. It is also used to approximate the Binomial Distribution when the number of events (N) is large and the probability that an event will happen (p) is small i.e., a general rule of thumb is for  $p \le .1$  and  $\hat{\lambda} = \hat{N}p \leq 5.$ 

Reference: Mathematical Statistics

by John E. Freund

1962 Prentice-Hall

ENTER PROGRAM (Starting Address is 0 - 0)

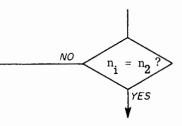
PRESS: GO TO (0) (0) or END

PRESS: CONTINUE

► ENTER DATA:  $n_2$  → Z,  $n_1$  → Y,  $\hat{\lambda}$  → X

►PRESS: CONTINUE

DISPLAY



-PRESS: CONTINUE

A Poisson distribution is given by

$$f(n; .72) = \frac{(.72)^n e^{-.72}}{n!}$$

Find: a) f(0; .72)

$$\hat{\lambda} = .72$$
,  $n_1 = 0$ ,  $n_2 = 0$   
 $f(0; .72) = .48675226$ 

$$\hat{\lambda} = .72, n_1 = 3, n_2 = 3$$

$$f(3;.72) = .03027988$$

If 3% of the electric bulbs manufactured by a company are defective find the probability that in a sample of  $100\ \text{bulbs}$ 

a) Between 1 and 3 bulbs will be defective.

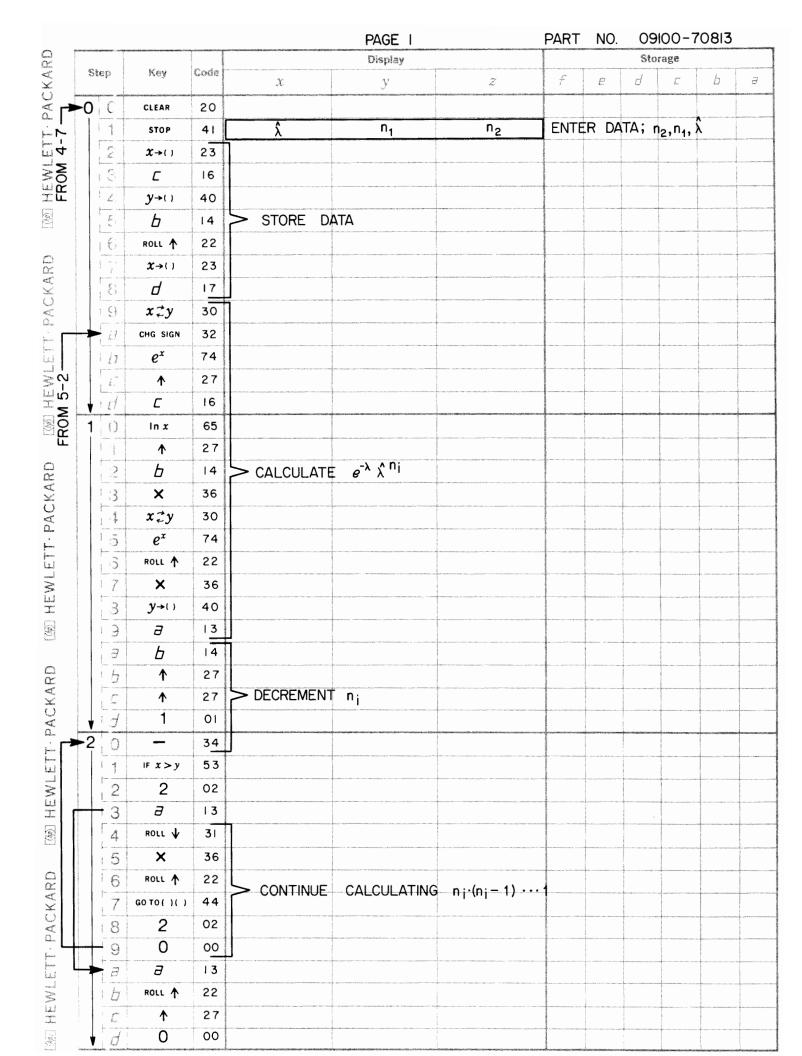
$$\sum_{n=1}^{3} f(n;3) = .59744482$$

where 
$$\stackrel{\wedge}{\lambda}$$
 = 3,  $n_1$  = 1,  $n_2$  = 3

b) Less than or equal to 2 bulbs are defective

$$\sum_{n=0}^{2} f(n;3) = .42319008$$

where 
$$\hat{\lambda} = 3$$
,  $n_1 = 0$ ,  $n_2 = 2$ 



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#### RANDOM NUMBER GENERATOR

PART NO. 09100-70816

This program calculates random numbers (RN) in the range 0  $\leq$  RN $_i$   $\leq$  1 using the formula given below:

$$RN_i = \left[\pi + RN_{(i-1)}\right]^8 - Int. \left\{ \left[\pi + RN_{(i-1)}\right]^8 \right\}$$

 $RN_i$  is the current random number and  $RN_{(i-1)}$  is the last calculated random number. More than 10,000 random numbers may be generated before values are repeated.

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PART NO. 09100-70904

#### NORMAL CURVE PLOT

This program generates a normal curve given mean  $M_h$  and variance  $\sigma_h^2$ . The program determines Y from:

$$Y = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(h - M_h)^2}{2\sigma_h^2}}$$

by varying h from 0 to 10 in increments of 0.1. The program requires that  $M_h$  and  $\sigma_h^2$  be stored in the f and e registers respectively prior to execution. This program was intended to be used in conjunction with program 09100-70905 Histogram Generation (with Plot). To plot in units of centimeters, place a 2 in locations (2) (5) and (2) (c).

SET: Decimal Wheel at 6 or less

Using the orgin controls, locate the pen at X = 1 in., Y = 1 in.

ENTER PROGRAM: (Starting Address is 0-0)

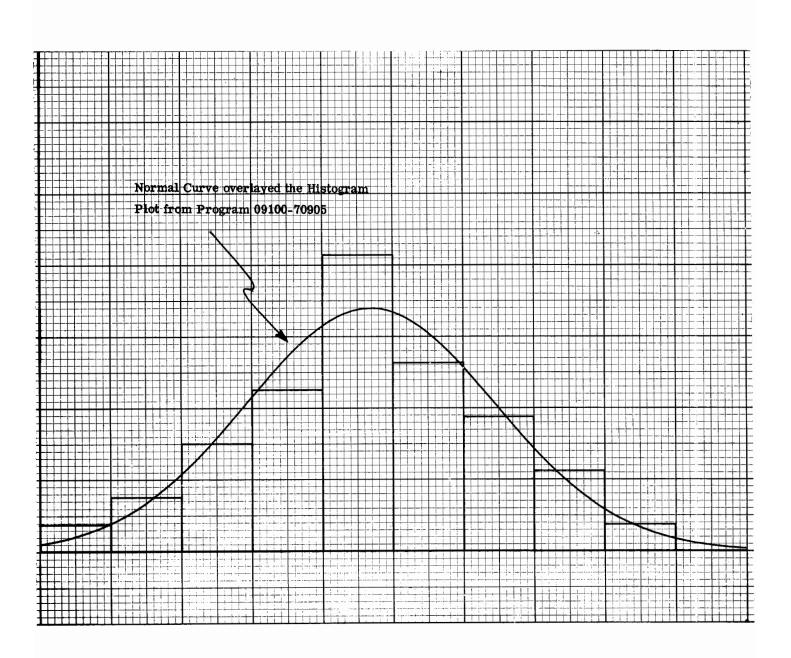
PRESS: END

PRESS: CONTINUE

 $\mathbf{M_h} = \mathbf{4.679}$ 

 $\sigma_{\rm h}^2 = 3.132$ 

See plot below



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PART NO. 09100-70907

#### ONE WAY ANALYSIS OF VARIANCE m x n

This program separates the total variance in a table of data into a portion due to chance and a portion due to differences between and population means underlying each column of sample data. It then calculates the variance ratio.

$$\mathbf{F} = \frac{n\mathbf{m}(\mathbf{m} - 1) \qquad \sum_{\substack{j=1 \\ \mathbf{i} = 1}}^{n} \qquad (\mathbf{X}_{j} - \overline{\mathbf{X}})}{\sum_{\substack{i=1 \\ \mathbf{i} = 1}}^{m} \qquad \sum_{\substack{j=1 \\ \mathbf{i} = 1}}^{n} \qquad (\mathbf{X}_{ij} - \overline{\mathbf{X}}_{j})$$

with

 $\nu_1$  = n - 1 degrees of freedom

 $\nu_2$  = n (m - 1) degrees of freedom

where

$$\overline{\mathbf{X}} = \frac{1}{mn}$$
  $\sum_{i=1}^{m}$   $\sum_{j=1}^{n}$   $\mathbf{X}_{i}$ 

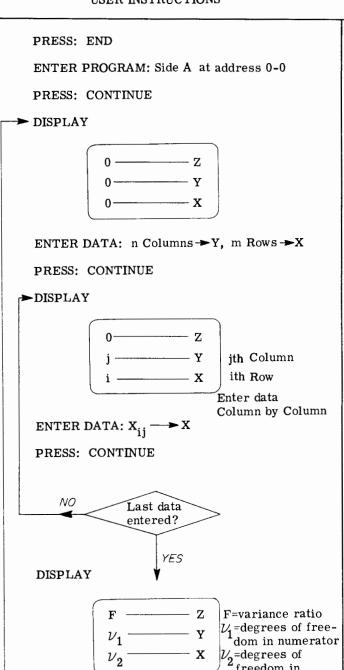
$$\overline{X}_j = \frac{1}{n} \qquad \int_{j=1}^{n} X_{ij}$$

The equation used by the program is:

$$F = \frac{nm(m-1) \quad \left\{ \sum\limits_{j=1}^{n} \quad \left[ \sum\limits_{i=1}^{m} X_{ij} \right]^{2} \quad - \frac{1}{mn} \quad \left[ \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} X_{ij} \right]^{2} \right\}}{..(n-1) \left\{ \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} X_{ij} \quad - \frac{1}{mn} \quad \left[ \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} X_{ij} \right]^{2} \quad - \frac{1}{m} \quad \sum\limits_{j=1}^{n} \left[ \sum\limits_{i=1}^{m} X_{ij} \right]^{2} + \frac{1}{mn} \left[ \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} X_{ij} \right]^{2} \right\}}$$

Reference: Freund, John E., Mathematical Statistics, Prentice Hall (1962)

#### EXAMPLE



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m	x <sub>m1</sub>						X <sub>mn</sub>

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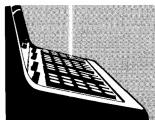
$$F = 5.01$$

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9100B ONLY PART NO. 09100-70901

#### MULTIPLE LINEAR REGRESSION

This program fits any number of data points  $(X_i, Y_i, Z_i)$  to a linear, two variable equation of the form:

$$Z = a_0 + a_1 X + a_2 Y$$

where X and Y are the independent variables.

#### Development:

The constants  $a_1$ ,  $a_1$ , and  $a_2$  of the equation may be found by solving simultaneously the following normal equations which represent the least square plane (approximating plane) formed by the data points.

$$\sum Z = a_0 n + a_1 \sum X + a_2 \sum Y$$

$$\sum XZ = a_0 \sum X + a_1 \sum X^2 + a_2 \sum XY$$

$$\sum YZ = a_0 \sum Y + a_1 \sum XY + a_2 \sum Y^2$$

In the program the constant  $a_2$  is found from solving the equations by matrix algebra. Therefore,

$$\mathbf{a_2} = \frac{-\mathrm{n}(\sum \mathbf{x^2} \sum \mathbf{yz} - \sum \mathbf{xz} \sum \mathbf{xy}) - \sum \mathbf{x}(\sum \mathbf{x} \sum \mathbf{yz} - \sum \mathbf{y} \sum \mathbf{xz}) + \sum \mathbf{z}(\sum \mathbf{x} \sum \mathbf{xy} - \sum \mathbf{y} \sum \mathbf{x^2})}{\mathrm{D}}$$

Where D (the determinant) = 
$$\begin{bmatrix} n & \sum X & \sum Y \\ \sum x & \sum x^2 & \sum xY \\ \sum Y & \sum xY & \sum Y^2 \end{bmatrix}$$

After finding a2, the solution is reduced to two equations in two unknowns which are:

$$M = a_0 n + a_1 \sum X$$

$$N = a_0 \sum X + a_1 \sum X^2$$

where 
$$M = (\sum Z - a_2 \sum Y)$$
  $N = (\sum XZ - a_2 \sum XY)$ 

These two equations are then solved for  $a_0$  and  $a_1$ .

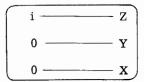
Reference:

Introduction to the Theory of Statistics Mood and Graybill McGraw-Hill, 1963 PRESS: END

ENTER PROGRAM: Side A followed by Side B

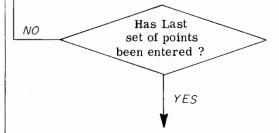
➤ PRESS: CONTINUE

**►** DISPLAY



ENTER DATA:  $Z_i \longrightarrow Z$ ,  $Y_i \longrightarrow Y$ ,  $X_i \longrightarrow X$ 

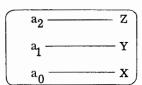
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PRESS: SET FLAG

PRESS: CONTINUE

DISPLAY



To reset problem, PRESS: CONTINUE

(A) Equation of the form:

$$Z = a_0 + a_1 X + a_2 Y$$

Input data:

Х	Y	Z
1	0	3
0	1	4
1	1	6
3	4	19
2	2	11

Solution:

$$Z = 1 + 2X + 3Y$$

(B) Equation of the form:

$$Z = a_0 + a_1(\log X) + a_2(\log Y)$$

Note to enter data;

ENTER: Z<sub>i</sub> 
$$\longrightarrow$$
 X
PRESS:  $\uparrow$ 
ENTER: Y<sub>i</sub>  $\longrightarrow$  X
PRESS: log X
PRESS:  $\uparrow$ 
ENTER: X<sub>i</sub>  $\longrightarrow$  X
PRESS: log X

Input data:

X	Y	Z
1 1 4 10 8 13 3	2 1 3.63 5 16 7	4.6505 4.5 5.9841 6.8495 6.9082 7.1504 5.9542

Solution:

$$Z = 4.5 + 2 (\log X) + .4999 (\log Y)$$

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# WEIBULL DISTRIBUTION PARAMETER CALCULATION FOR FAILURE DATA

9100B ONLY PART NO. 09100-70902

The Weibull probability density function is given by

$$f(X) = \frac{bX^{(b-1)}}{\theta^b} e^{-(\frac{X}{\theta})^b}$$

and the cummulative distribution function is given by

$$F(X) = I - e^{-\left(\frac{X}{\theta}\right)^{b}}$$

For a set of data, the Weibull parameters b and  $\theta$  are to be calculated for these functions.

A common application is to use Weibull analysis for failure data where all samples are tested to failure. To use the program, list the items in order of increasing time to failure. The number of items and times to failure are entered. The parameters b,  $\theta$ , and r are displayed. r is a correlation coefficient indicating goodness of fit. The time required for  $10\%~(B_{10})$  to fail is displayed and times to other failure percentages (B%) may be requested.

The Median Rank (M.R.) is calculated by the equation

$$M.R. = \frac{j - .3}{N + 4}$$

where j = failure order number

N = number of samples tested

This is an approximation of F(X).

The commulative distribution function is linearized into the form

$$bLnX - bLn\theta = LnLn\left(\frac{1}{1-F(X)}\right)$$

A least squares fit is performed which calculates the slope, intercept, and correlation coefficient. The solution is similar to the linear regression program 09100-70803. Thus estimates of b and  $\theta$  are obtained.

#### PRESS: END

ENTER PROGRAM: Side A followed by Side B

→ PRESS: CONTINUE

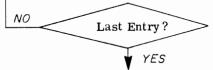
ENTER DATA: N → X

➤PRESS: CONTINUE

DISPLAY

(j indicates point to be entered)

ENTER DATA:  $t_j \longrightarrow X$  (Data must be ordered)



PRESS: CONTINUE

DISPLAY

➤ PRESS: CONTINUE

DISPLAY

(first time will be 10%)

-ENTER DATA: % --> X

TO RESTART A NEW PROBLEM

PRESS: END

ΤE	ST	$\mathbf{D}^{A}$	$\Lambda T_A$	A

Hours to failure (must be ordered)

34

60

N = 6 (number of samples)

95

119

158

r = .999

 $\theta = 104.091$ 

b = 1.953

 $B_{10} = 32.887$ 

 $B_{90} = 159.539$ 

410					Page	e <b>1</b>				PAR	T NO.	091	100-	70902	ç	1001	B ON	LY
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# NON-LINEAR REGRESSION THE LEAST SQUARE PARABOLA

9100B ONLY PART NO 09100-70903

Development:

The least square parabola approximating the set of points  $(\mathbf{X}_1,\ \mathbf{Y}_1)$  . . . .  $(\mathbf{X}_i,\ \mathbf{Y}_i)$  has the equation:

$$Y = a_0 + a_1 x + a_2 x^2$$

where the constants  $a_0$ ,  $a_1$ , and  $a_2$  are determined by solving simultaneously the following normal equations:

$$\Sigma Y = a_0 n + a_1 \Sigma X + a_2 \Sigma X^2$$

$$\Sigma XY = a_0 \Sigma X + a_1 \Sigma X^2 + a_2 \Sigma X^3$$

$$\Sigma X^2 Y = a_0 \Sigma X^2 + a_1 \Sigma X^3 + a_2 \Sigma X^4$$

In the program the constant  $a_2$  is found by matrix algebra; the determinate (D) involved in the solution is:

$$D = \begin{bmatrix} n & \sum x & \sum x^2 \\ \sum x & \sum x^2 & \sum x^3 \\ \sum x^2 & \sum x^3 & \sum x^4 \end{bmatrix}$$

The equation for a<sub>2</sub> is therefore:

$$\mathbf{a_2} = \underbrace{\left(\mathbf{n}(\boldsymbol{\Sigma} \mathbf{X}^2 \boldsymbol{\Sigma} \mathbf{X}^2 \mathbf{Y} - \boldsymbol{\Sigma} \mathbf{X}^3 \boldsymbol{\Sigma} \mathbf{X} \mathbf{Y}) - \boldsymbol{\Sigma} \mathbf{X}(\boldsymbol{\Sigma} \mathbf{X} \boldsymbol{\Sigma} \mathbf{X}^2 \mathbf{Y} - \boldsymbol{\Sigma} \mathbf{X}^2 \boldsymbol{\Sigma} \mathbf{X} \mathbf{Y}) + \boldsymbol{\Sigma} \mathbf{Y} \left[\boldsymbol{\Sigma} \mathbf{X} \boldsymbol{\Sigma} \mathbf{X}^3 - (\boldsymbol{\Sigma} \mathbf{X}^2)^2\right]\right)}_{\mathbf{D}}$$

After finding  $a_{2}$  the solution is reduced to two equations in two unknowns which are:

$$N = a_0 n + a_1 \Sigma X$$

$$M = a_0 \Sigma X + a_1 \Sigma X^2$$

$$N = \Sigma Y - a_2 \Sigma X^2$$

where  $M = \sum XY - a_2 \sum X^3$ 

These equations are then solved for  $a_0$  and  $a_1$ .

NOTE: Curves with the following equations may also be fitted with this program:

and

$$Y = a_0 + a_1 X \tag{1}$$

$$\log Y = a_0 + a_1 X \tag{2}$$

$$\log Y = a_0 + a_1 X + a_2 X^2 \tag{3}$$

$$Y = a_0 + a_1 \log X \tag{4}$$

$$\log Y = a_0 + a_1 \log X \tag{5}$$

$$\log Y = a_0 + a_1 (\log X) + a_2 (\log X)^2$$
 (6)

An equation of the form of (6) is solved in the examples.

The general form, representing all of these equations, which can be fitted is:

$$f(Y) = a_0 + a_1 f(X) + a_2 f^2(X)$$

Reference:

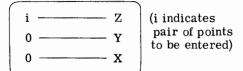
Publisher -- McGraw-Hill Authors -- Alexander M. Mood & Franklin A. Graybill Introduction into the Theory of Statistics -- 2nd Edition (1961) PRESS: END

ENTER PROGRAM: Side A followed by Side B

PRESS: END

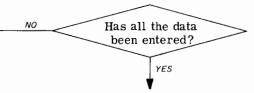
➤ PRESS: CONTINUE

**→**DISPLAY



ENTER DATA:  $Y_i \rightarrow Y$ ,  $X_i \rightarrow X$ 

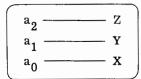
PRESS: CONTINUE



PRESS: SET FLAG

PRESS: CONTINUE

DISPLAY



To calculate coefficients for new data:

-PRESS: END

(A) Equation of the form:  $Y = a_0 + a_1 X + a_2 X^2$ 

Data:

X	Y
3	29
0	2
3 0 5 2	67
2	16
1.5	11
4	46
1	7

Solution:  $Y = 2 + 3X + 2X^2$ 

(B) Equation of the form:  $\log Y = a_0 + a_1 \log X + a_2 (\log X)^2$ 

Note: Data to be entered is  $\log Y_i$ ,  $\log X_i$ ; therefore to enter data sets:

ENTER:  $Y_1 \longrightarrow X$ PRESS:  $\log X$ PRESS:  $\uparrow$ ENTER:  $X_1 \longrightarrow Y$ PRESS:  $\log X$ 

Data:

X	Y
1 2 3 4	2.7183 35.1595 245.3746 1188.7946
5	4530.5750

Solution:  $\log Y = .43 + 3.0 \log X + 2.30 (\log X)^2$ 

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9100B ONLY PART NO. 09100-70905

#### HISTOGRAM GENERATION (WITH PLOT)

This program generates and plots a histogram of ten windows given a data set of positive numbers. In addition, it determines the mean  $(M_{\chi})$  and the variance  $(\sigma_{\chi}^2)$  of the raw data, and the mean  $(M_h)$  and the variance  $(\sigma_h^2)$  of the normalized histogram data. Since the raw data is normalized by the program to values  $0 \le h \le 10$ , the new mean and variance are given by

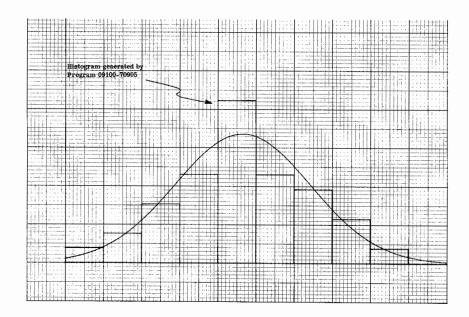
$$M_{h} = \frac{M_{x}}{W}$$

$$\sigma_{h}^{2} = \frac{\sigma_{x}^{2}}{W^{2}}$$

where W is the histogram window width (normalizing factor)\*. The program plots the histogram and stores  $M_h$  and  $\sigma_h 2$  for use by program 09100-70904 which can be used to plot a normal curve over the histogram.

This program uses Indirect Addressing and is self-destructing of the registers +(0,0) through +(d,d). Thus, to rerun, the A side must be re-entered in the calculator.

NOTE: To generate a histogram with 1 cm. wide windows, place 2's in locations (-)(6)(c), (-)(7)(6), and (-)(8)(5).



\* The window width W is chosen such that all normalized data entries X/W will lie between 0 and 10. Thus, if the data ranges from  $0 \longrightarrow 200$ , a W of of 20 would be proper.

PRESS: END

Using the orgin controls, locate the pen at X = 1 in., Y = 1 in.

SET: Decimal Wheel at 6 or less

ENTER PROGRAM: Side A followed by Side B

PRESS: CONTINUE

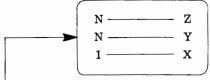
DISPLAY



ENTER DATA: W→ X

PRESS: CONTINUE

DISPLAY



N is the number of data points entered.

ENTER DATA:  $X_N \rightarrow X$ 

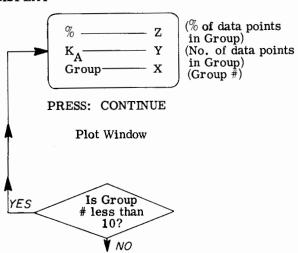
PRESS: CONTINUE



PRESS: SET FLAG

PRESS: CONTINUE

# DISPLAY

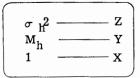


DISPLAY

$$\begin{bmatrix}
\sigma_{\chi}^2 & --- & Z \\
M_{\chi} & --- & Y \\
0 & --- & X
\end{bmatrix}$$

PRESS: CONTINUE

DISPLAY



**EXAMPLE** 

The data set is:

104, 92, 83, 78, 58, 135, 146, 24, 74, 85, 81, 128, 140, 113, 79, 78, 53, 42, 34, 85, 96, 110, 133, 158, 171, 108, 84, 90, 73, 11, 51, 118, 68, 139, 92, 109, 89, 124, 91, 116.

The data varies between 0 and 200 so W is chosen to be 20.

### Result

Group	K <sub>A</sub>	%	
1	1	2.5	
2	2	5.	
3	4	10	
4	6	15.	
5	11	27.5	N = 40
6	7	17.5	
7	5	12.5	
8	3	7.5	
9	1	2.5	
10	0	0	
	ł	1	

$$\sigma_{x}^{2}$$
 = 1252.644  $\sigma_{h}^{2}$  = 3.132  $M_{x}$  = 93.575  $M_{h}$  = 4.679

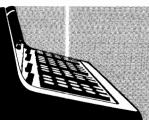
The histogram plot is given with the normal curve superimposed. The normal curve resulted from running program 09100-70904 following completion of the Histogram Generation program.

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9100B ONLY PART NO. 09100-70906

# HISTOGRAM GENERATION (WITHOUT PLOT)

This program generates a histogram table of ten windows given a data set of positive numbers. In addition, it determines the mean  $(M_{\underline{x}})$  and the variance  $(\sigma_{\underline{x}}2)$  of the raw data, and the mean  $(M_{\underline{h}})$  and variance  $(\sigma_{\underline{h}}2)$  of the normalized histogram data. Since the raw data is normalized by the program to values  $0 \le h \le 10$ , the new mean and variance are given by

$$M_h = M_X$$

$$\sigma_h^2 = \frac{\sigma_x^2}{W^2}$$

where W is the histogram window width (normalization factor). The window width W is chosen such that all normalized data entries X/W will lie between 0 and 10. Thus, if the data ranges from 0  $\longrightarrow$  200, a W of 20 would be proper.

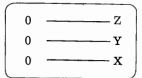
This program uses Indirect Addressing. The (+) registers are used for storage whereas the (-) registers are used for program steps.

ENTER PROGRAM: (Starting Address is (-0)(0))

PRESS: GO TO (-) (0) (0)

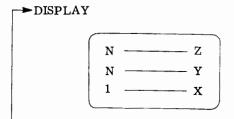
PRESS: CONTINUE

DISPLAY



ENTER DATA: W → X

PRESS: CONTINUE

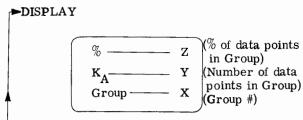


ENTER DATA: X → X PRESS: CONTINUE

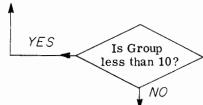


PRESS: SET FLAG

PRESS: CONTINUE

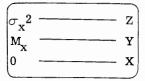


PRESS: CONTINUE



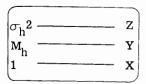
PRESS: CONTINUE

DISPLAY



PRESS: CONTINUE

DISPLAY



PRESS: GO TO

PRESS: —

To consider another set of data.

PRESS: 0

PRESS: 0

EXAMPLE

The data set is:

104, 92, 83, 78, 58, 135, 146, 24, 74, 85, 81, 128, 140, 113, 79, 78, 53, 42, 34, 85, 96, 110, 133, 158, 171, 108, 84, 90, 73, 11, 51, 118, 68, 139, 92, 109, 89, 124, 91, 116.

The data varies between 0 and 200 so W is chosen to be 20.

Result

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$$\sigma_{\rm X}^2$$
 = 1252.644  $\sigma_{\rm h}^2$  = 3.132  $M_{\rm h}$  = 93.575  $M_{\rm h}$  = 4.679

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-DISTRIBUTION

PART NO.

This program evaluates the integral of the F distribution density function

$$Q = \int_{\Gamma} \frac{\infty \Gamma\left(\frac{V_1 + V_2}{2}\right) - X^{V_1/2^{-1}} - \left(\frac{V_1}{V_2}\right)^{-V_1/2}}{\Gamma\left(\frac{V_1}{2}\right) - \Gamma\left(\frac{V_2}{2}\right) \left(1 + \frac{V_1}{V_2} - X\right) - \frac{V_1 + V_2}{2}} dx$$

for given values of F,  $\mathbf{V_1}$ ,  $\mathbf{V_2}$  .

The integral is evaluated by means of the following series:

 $V_2$  EVEN

$$Q (F/V_1, V_2) = 1 - (1 - X)^{V_{1/2}} \left[ 1 + \frac{V_1^X}{2} + \dots + \frac{V_1(V_1 + 2) \dots (V_2 + V_1 - 4)}{2 \cdot 4 \dots (V_2 - 2)} X^{\frac{V_2 - 2}{2}} \right]$$

V<sub>2</sub> ODD

Q (F / 
$$V_1$$
,  $V_2$ ) = X  $V_{2/2} \left[ 1 + \frac{V_2}{2} (1 - X) + \dots + \frac{V_2(V_2 + 2) \dots (V_2 + V_1 - 4)}{2 \cdot 4 \dots (V_1 - 2)} (1 - X) \right]$ 

 $\frac{V_1 \text{ and } V_2 \text{ both odd}}{Q(F/V_1, V_2) = 1 - A + B}$ 

$$\mathbf{A} = \begin{cases} \frac{2}{\pi} \left\{ \theta + \sin \theta \cos \theta \left[ 1 + \frac{2}{3} \cos^2 \theta + \dots + \frac{2 \cdot 4 \cdot \dots \cdot (\mathbf{V_2} - 3)}{3 \cdot 5 \cdot \dots \cdot (\mathbf{V_2} - 2)} \cos^{-\frac{1}{2} \theta} \right] \right\} & \mathbf{V_2} > 1 \\ \frac{2 \cdot \theta}{\pi} & \mathbf{V_2} = 1 \\ \theta = -\operatorname{Arc} \operatorname{Tan} \sqrt{\frac{\mathbf{F}}{\mathbf{V_2}}} \end{cases}$$

$$B = \begin{cases} \frac{2\left(\frac{V_{2}-1}{2}\right)!}{\sqrt{\pi}\left(\frac{V_{2}-2}{2}\right)!} & \sin\theta & 1 & \cos^{2}\theta_{1} \\ = 0 & V_{1} & = 1 \\ \theta_{1} & = \text{Arc Tan} & \sqrt{\frac{V_{1}F}{V_{2}}} \end{cases} & \sin\theta & 1 & \cos^{2}\theta_{1} \\ & \cos^{2}\theta_{1} & \sin^{2}\theta_{1} & \sin^{2}\theta_{1} & \cos^{2}\theta_{1} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{2} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{2} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{2} & \cos^{2}\theta_{2} \\ & \cos^{2}\theta_{1} & \cos^{2}\theta_{2} \\ & \cos^{2$$

Reference: Handbook of Mathématical Functions, Abromowitz and Stegun, National Bureau of Standards (1964)

SET:

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PRESS: END

ENTER PROGRAM: Side A followed by Side B

➤ PRESS: END

PRESS: CONTINUE

ENTER DATA:

F ratio  $\longrightarrow$  Z  $V_1$  for numerator  $\longrightarrow$  Y  $V_2$  for denominator  $\longrightarrow$  X

PRESS: CONTINUE

DISPLAY

$$\begin{pmatrix}
Q(F/V_{1}V_{2}) --Z \\
0 -----Y \\
0 ----X
\end{pmatrix}$$

To calculate significance level for new data.

General Form  $Q(F/V_1, V_2)$ 

Q(4.21/7, 6) = 0.05

Q(11.4/4, 5) = 0.01

Q(3.79/7, 7) = .05

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9100B ONLY PART NO. 09100-70909

# TWO WAY ANALYSIS OF VARIANCE (m x 4)

This program analyzes the total statistical variance in a table of data by separating the total variance into two parts, the variance among rows of data, and the variance between columns of data, and comparing each to the variance due to random influence. In a table of four columns and m rows it calculates the variance ratio between columns.

$$F_{c} = \frac{\sum_{j=1}^{4} (\bar{x}_{j} - \bar{x})^{2}}{\sum_{j=1}^{4} \sum_{j=1}^{m} (x_{ij} - \bar{x}_{j} - \bar{x}_{i} + \bar{x})^{2}} (m-1) (3)$$

with  $V_1 = 3$  degrees of freedom

and  $V_2 = 3 (m-1)$  degrees of freedom

and the variance ratio between rows:

$$F_{r} = \frac{4 \sum_{i=1}^{m} (\bar{X}_{i} - \bar{X})^{2} (m-1)}{\sum_{j=1}^{4} \sum_{i=1}^{m} (X_{ij} - \bar{X}_{j} - \bar{X}_{i} + \bar{X})^{2} 3 (m-1)}$$

with  $V_1 = m-1$  degrees of freedom  $V_2 = 3 (m-1)$  degrees of freedom

where:

$$\overline{X}_{j} = \frac{1}{m} \sum_{i=1}^{m} X_{ij}$$

$$\overline{X} = \frac{1}{4m} \quad \sum_{j=1}^{4} \quad \sum_{i=1}^{m} \quad X_{ij}$$

$$\overline{X}_{i} = \frac{1}{4} \sum_{j=1}^{4} X_{ij}$$

$$V_1$$
 = degrees of freedom in numerator  $V_2$  = degrees of freedom in denominator

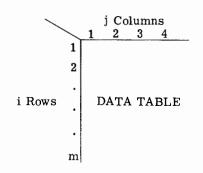
The equations used by the program are:

$$\mathbf{F_{r}} = \frac{4(m-1)\left\{\frac{1}{4}\sum\limits_{i=1}^{m}\left[\sum\limits_{j=1}^{4}X_{ij}\right]^{2} - \frac{1}{4m}\left[\sum\limits_{j=1}^{4}\sum\limits_{i=1}^{m}X_{ij}\right]^{2}\right\}}{3\left\{\sum\limits_{j=1}^{4}\sum\limits_{i=1}^{m}X_{ij}^{2} - \frac{1}{4m}\left[\sum\limits_{j=1}^{4}\sum\limits_{i=1}^{m}X_{ij}\right]^{2} - \frac{1}{m}\sum\limits_{j=1}^{4}\left[\sum\limits_{i=1}^{m}X_{ij}\right]^{2} - \frac{1}{4}\sum\limits_{i=1}^{m}\left[\sum\limits_{j=1}^{4}X_{ij}\right]^{2} + \frac{1}{2m}\left[\sum\limits_{j=1}^{4}\sum\limits_{i=1}^{m}X_{ij}\right]^{2}\right\}}$$

$$F_{c} = \frac{3m\left\{\frac{1}{m} \int_{j=1}^{4} \left[\sum_{i=1}^{m} x_{ij}\right]^{2} - \frac{1}{4m}\left[\sum_{j=1}^{4} \sum_{i=1}^{m} x_{ij}\right]^{2}\right\}}{(m-1)\left\{\sum_{j=1}^{4} \sum_{i=1}^{m} x_{ij}^{2} - \frac{1}{4m}\left[\sum_{j=1}^{4} \sum_{i=1}^{m} x_{ij}\right]^{2} - \frac{1}{m} \sum_{j=1}^{4} \left[\sum_{i=1}^{m} x_{ij}\right]^{2} - \frac{1}{4} \sum_{i=1}^{m} \left[\sum_{j=1}^{4} x_{ij}\right]^{2} + \frac{1}{2m}\left[\sum_{j=1}^{4} \sum_{i=1}^{m} x_{ij}\right]^{2}\right\}}$$

Reference: Freund, John E., Mathematical Statistics, Prentice Hall (1962)

#### USER INSTRUCTIONS



PRESS: END

ENTER PROGRAM: Side A followed by Side B

PRESS: END

► PRESS: CONTINUE

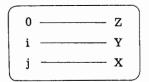
DISPLAY



ENTER DATA: m → X number of rows in data table

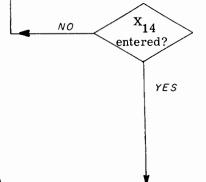
PRESS: CONTINUE

DISPLAY



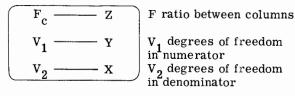
ENTER DATA: X<sub>ij</sub> X j = column i = row (data entered row by row)

PRESS: CONTINUE



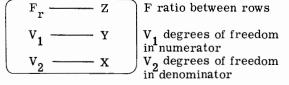
# USER INSTRUCTIONS (Con't)

DISPLAY



PRESS: CONTINUE

DISPLAY

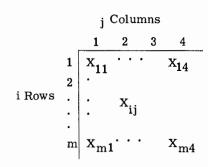


To re-run program:

←PRESS: END

#### **EXAMPLE**

General form



		Colun	nns	
	58.2	49.1	60.1	<b>75.</b> 8
Rows	56.2	54.1	70.9	58. <b>2</b>
	65.3	51.6	39.2	48.7
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F =	0.92	V = 2	V =	6

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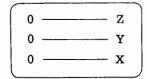
PRESS: END

ENTER PROGRAM 1: Side A followed by Side B

PRESS: END

PRESS: CONTINUE

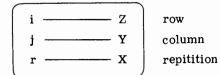
DISPLAY



ENTER DATA: rows columns repetitions  $k \longrightarrow Z$ ,  $n \longrightarrow Y$ ,  $m \longrightarrow X$ 

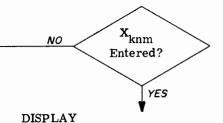
PRESS: CONTINUE

#### → DISPLAY



ENTER DATA: X<sub>iir</sub> → X

PRESS: CONTINUE



?\*)(? — Z 0 — Y 0 — X

ENTER PROGRAM 2: Starting Address is (-)(0)(0)

PRESS: GO TO

PRESS: -

PRESS: 0

PRESS: 0

PRESS: CONTINUE

DISPLAY

$$\left(\begin{array}{cccc} \mathbf{F}_{row} & ---- & \mathbf{Z} \\ \mathbf{V}_1 & ---- & \mathbf{Y} \\ \mathbf{V}_2 & ---- & \mathbf{X} \end{array}\right)$$

PRESS: CONTINUE

DISPLAY

PRESS: CONTINUE

DISPLAY

$$\begin{array}{ccc} \mathbf{F_{interaction}} & \mathbf{Z} \\ \mathbf{V_1} & & \mathbf{Y} \\ \mathbf{V_2} & & \mathbf{X} \end{array}$$

# EXAMPLE

	n	= 3 colu	ımns	
	58.2	56.2	65.3	
	52.6	41.2	60.8	
	49.1	54.1	51.6	
1- 4	42.8	50.5	48.4	
k = 4  rows <	60.1	70.9	39.2 <sub>\</sub>	m = 2
	58.3	73.2	${39.2 \atop 40.7}$	repititions
	75.8	58.2	48.7	
	75.8 71.5	51.0	41.4	

Results:

$$F_{row} = 4.42$$
  $F_{column} = 9.39$   $V_1 = 3$   $V_1 = 2$   $V_2 = 12$   $V_2 = 12$   $F_{interaction} = 14.93$   $V_1 = 6$   $V_2 = 12$ 

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