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Multivariate Analysis, Retrieval, and Storage System (MARS)

Vol. I, MARS System and Analysis Techniques

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PREFACE

This report was prepared under Task II of Contract NAS2-7627, "Further Flight Mechanics and Vehicle Synthesis Research", in the period from June 1973 to May 1974. Mr. Michael J. Tauber was the NASA technical monitor for this study which was done for the Advanced Concepts Branch of the Aeronautics Division of National Aeronautics and Space Administration's Ames Research Center. Mr. Donald S. Hague, of Aerophysics Research Corporation, served as project leader for this study.

In the aerospace vehicle preliminary design process the estimation of subsystem component weights and costs are based on formulae obtained by multivariate correlation-regression analyses of historical data. While many groupings of such formulae have been presented in the past, there exists a need for a rapid method of verifying and improving these formulae in specific applications. The Multivariable Data Analysis, Retrieval, and Storage System (MARS) fulfills this function. In the MARS system selected vehicle characteristics information has been stored in a computerized data base. The data can be displayed, retrieved, or analyzed for functional relationships by multivariable statistical correlation-regression analyses using any specified subset of characteristics and vehicles.

This report, Volume I of the Task II documentation outlines the MARS system, its operation, and the contents of the MARS data bases which contain the characteristics of existing aircraft and engines.

SUMMARY

Aerospace vehicle and vehicle component weight estimates are necessarily based on historical data during preliminary design definition. Collections of formulae for carrying out these weight estimations have been established at all manufacturing establishments and at government centers concerned with vehicle preliminary design. These formulae are based on multivariate correlation-regression analyses using the characteristics from a large aggregate of diverse vehicle designs. As such, their applicability to a specific new design must be carefully examined in each application. Therefore a method for rapidly examining the probable applicability of weight estimating formulae to a specific design is required. The Multivariate Analysis Retrieval and Storage System (MARS) fills this requirement. The MARS system consists of three computer programs which sequentially operate on the weight and geometry characteristics of past aerospace vehicle designs. These programs are:

1. A data base storage and retrieval module,
2. A multivariate correlation-regression analysis module, and
3. A graphical display module.

Weight and geometric characteristics are stored in a set of data bases which are fully computerized. Separate data bases are currently being maintained for four vehicle and vehicle component classes. These are:

1. Military Flight Vehicles
2. Civil Transports
3. Turbojet and Turbofan Aircraft
4. General Aviation Light Aircraft

Additional data bases are readily added to the MARS system and/or the existing data bases may be easily expanded to include additional vehicles or vehicle characteristics.

In a given application of the MARS system, the vehicle designer or design team makes the following decisions:

1. Which vehicle set from those vehicles stored is applicable to the current design?

2. What component weights are to be estimated?
3. What are the probable component weight characteristic dependencies?

Given these three decisions the MARS system carries out a set of computerized correlation-regression analyses as follows. The selected vehicle sample is automatically removed from the MARS data base together with the characteristics on which the correlation is sought. Component weight estimating relationships are obtained in the form

$$\Delta W = aX_1^{b_1} X_2^{b_2} --- X_n^{b_n}$$

Where ΔW is the component weight, the X_i are the characteristic variables selected, and a, b_i are the regression coefficients. The degree of correlation is presented both in the form of conventional statistical measures and graphically by automatically plotting scatter diagrams comparing actual and predicted component weights.

The basic MARS system reported here is programmed on the IBM 360/67 digital computer system with graphical output on IMLAC cathode ray tube plotting device or ZETA X-Y plotting device for hard copy. A CDC6600 version without graphics capability is also available. The system has been operational for one year at the time of this report.

MULTIVARIATE ANALYSIS, RETRIEVAL, AND STORAGE SYSTEM (MARS)

VOLUME I MARS SYSTEM AND ANALYSIS TECHNIQUES

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INTRODUCTION

Preliminary weight estimates for advanced aerospace vehicle systems are necessarily based on historic data from previous designs. Usually weight characteristics of these past designs are subjected to a correlation-regression analysis and a series of formulae for vehicle and vehicle component weights are derived. Typically the form of these equations is:

$$W_i = a_i X_{1i}^{b_{1i}} X_{2i}^{b_{2i}} - - - X_{ni}^{b_{ni}}$$

$$i = 1, 2, -,-, N$$

where

W_i is the weight estimate for component i.

a_i is the multiplicative constant for component i weight estimation.

b_{r_i} is the r^{th} exponential constant for estimating the weight of component i.

X_{r_i} is the rth independent variable on which the weight of component i is assumed to depend.

Weight estimating relationships (WER) of this form have been tabulated at all major aerospace vehicle manufacturing establishments. Frequently these WER are considered to be of a proprietary nature and hence are not widely distributed. Exceptions to this situation have been created where the government has undertaken to fund contracted research in the field of weight estimation. For example, WER's for military flight vehicles and for transport vehicles have been reported in references 1 and 2. A series of modified WER based on this work is reported in references 3 and 4 where expressions are derived for the component weights of

1. **Air-to-surface missiles**
2. **Hypersonic transports and Space Shuttle Vehicles**

3. Remotely piloted vehicles
4. Light weight fighters
5. Military flight vehicles
6. Subsonic transports
7. General aviation light aircraft
8. Lifting bodies of the X-24 vehicle series

These relationships are based on an analysis of a large aggregate of vehicles in the particular class or on calibration of an existing WER using one member of a new vehicle class, Reference 5. In many new vehicle designs existing WER provide a close first approximation to component weights. However, in other instances the design team may undertake the development of new WER for a given preliminary design. Improved estimates may result from any of the approaches described below:

Reduced Set of Past Designs

Use of a reduced set of past designs which appear more representative of the new design than the ensemble of all aircraft of a particular type. For example, when estimating the basic weight of subsonic jet transport wings as in Reference 2, the design team may wish to drop all propeller driven transports from consideration. Or in the case of a swept wing military aircraft it might be desirable to eliminate all delta wing vehicles from consideration. Again, in the body of this report various groupings of turbojet and turbofan aircraft engines will be employed to derive engine WER for various engine classes.

Modified Independent Variable Set

Use of a modified set of independent variables for particular component weight WER. For example, the WER for estimating basic wing weight in References 1 and 2 do not consider a dependency on dynamic pressure. In a particular application it may be desirable to derive new WER which include dynamic pressure as an independent variable.

Weighting of Past Designs

Weighting of historical data for particular past designs. For example, in estimating component weights for delta winged military aircraft it may be desirable to retain the ensemble of all past designs but to weight those having delta wings by a higher factor than other vehicles.

Dangers of a Reduced Sample Set

Caution must be exercised in studies employing a reduced vehicle set. As the sample size diminishes, the correlation between actual and predicted component weights for sample members retained tends to improve. In the limit, when the sample size is reduced to N + 1, a WER will exactly predict the weight of all sample members retained for there are precisely N + 1 constants to be established in the mean square minimization procedure which forms the analytic basis of a correlation-regression analysis. To minimize the risk associated with sample size it is recommended that as a rough rule-of-thumb an analysis should employ on the order of 3N sample members when establishing a new WER.

Advantages of MARS System

Manually deriving new WER for particular vehicles can be a time-consuming process when data for new vehicle sets or additional component weight dependencies are numerically assembled. MARS eliminates the need for manual assembly of such data, the subsequent manual transmission of selected data to correlation-regression analyses, and for graphical display of the results. MARS is an automated system for vehicle characteristics retrieval, correlation-regression analysis, and graphical output display. New WER based on reduced vehicle sample size, modified independent variables, and vehicle weighting can be obtained in one short computer run together with graphical output depicting the agreement between actual and predicted weights for the selected sample. MARS is operational on the IBM 360/67 computer at the NASA Ames Research Center using remote entry terminals and on-line graphics output. The MARS system and its analytic basis is described in subsequent sections of this report.

THE MARS MULTIVARIATE ANALYSIS, RETRIEVAL, AND STORAGE SYSTEM

System Outline

The MARS Multivariate Analysis, Retrieval, and Storage System consists of the following elements:

1. An integrated system of computer programs for obtaining and displaying vehicle component weight correlations.
2. A set of data bases containing historical vehicle characteristic data.
3. Access to an IBM 360/67 digital computer for correlation-regression analysis calculations.
4. Access through remote job entry terminals for communication to the IBM 360/67.
5. An IMLAC cathode ray tube graphical display device with access to disc stored graphical output files.
6. An in-line hard copy ZETA plotter for final presentation of the correlations.

A schematic of the MARS system is presented in Figure 1. The IMLAC graphical display device and disc is shown in Figure 2 together with other elements used in the Ames Research Center IBM 360/67 installation.

MARS System Computer Programs

Three types of computer program are employed in the MARS system. These are:

1. A series of programs for data base manipulation. One such program is provided for each of four data bases.
2. A Correlation-Regression Multivariate analysis program. A single program operates on any data set obtained from the four data bases.

3. A graphics output program which prepares well ordered plots illustrating the accuracy of the correlation.

Each program is briefly outlined below. Figure 3 illustrates the operation of the program system in a schematic form.

Program WGTBAS - Military Aircraft

This program manipulates a data base containing weight and geometry characteristics of past military flight vehicle designs. Contents of this data base are discussed below. The program has the ability to perform the following functions:

1. Add additional vehicles to the data base.
2. Add additional vehicle characteristics to the data base.
3. Internally construct and store characteristics which are algebraic combinations of other characteristics in the data base.
4. Display all known information about any set or all of the vehicles. Figure 4 illustrates the form of this output for an F4-E aircraft.
5. Display the values taken on by any characteristics set for all vehicles or any subset of vehicles.

6. Retrieve up to ten vehicle characteristics sets for any subset of vehicles and construct an intermediate data base containing only those characteristics. This data base is subsequently operated on by the correlation-regression analysis program POWER described below.

Program TRNBAS - Transport Aircraft

This program manipulates a data base containing weight and geometry characteristics of transport aircraft. Program TRNBAS contains all capabilities of program WGTBAS described above. A typical output display is presented for a C130-A aircraft in Figure 5.

Program ENGBAS - Turbojet and Turbofan Engines

This program manipulates a data base containing weight and geometry characteristics of turbojet and turbofan engines. Program ENGBAS contains all capabilities of program WGTBAS described above. A typical output display is presented for the Pratt and Whitney J60-P-3 engine, which powers the T39A aircraft, in Figure 6.

Program GAVBAS - General Aviation Light Aircraft

This program manipulates a data base containing general aviation light aircraft characteristics. Program GAVBAS contains all capabilities of program WGTBAS described above. Date source is Brent Silver's Ph.D. thesis, reference 6.

Program ASMBAS

This program operates on a data base of calculated air-to-surface missile characteristics reported in Reference 7.

Program POWER

This program operates on the intermediate data base constructed by any of the programs WGTBAS, TRNBAS, ENGBAS, GAVBAS, or ASMBAS. Its function is to carry out a correlation-regression analysis using standard methods of statistical analysis described later with final result in the form

$$W_i = a_i X_1^{b_1} X_2^{b_2} - - - X_N^{b_N}$$

and to produce an intermediate graphics output file for the plotting program described below.

Program DISPLA

This program operates on the intermediate output file produced by program POWER. Its function is to provide a graphical display illustrating the degree of success obtained in the correlation-regression analysis. Calculated and actual weights are displayed on the IMLAC cathode ray tube device previously illustrated in Figure 2 or the ZETA plotter. Typical form of the final graphical output is presented in Figure 7.

MARS DATA BASES

Permanent and Dynamic Data Bases

The five permanent data bases of the MARS system are:

1. Military Flight Vehicle Data Base, M^1
2. Transport Data Base, M^2
3. Turbojet and Turbofan Data Base, M^3
4. General Aviation Light A/C Data Base, M^4
5. Calculated ASM Data Base, M^5

Each data base consists of a matrix of numbers $\left[M_{i_j}\right]$ where the row index i designates vehicle or engine type and the column index j designates a particular characteristic. Thus the i^{th} row $\lfloor M_i \rfloor$ contains all known information about the i^{th} vehicle or engine. The j^{th} column $\left\{M_j\right\}$ contains the values of a particular characteristic, such as length, for all vehicles or engines.

The first step in a correlation-regression analysis is to strip up to ten characteristic columns from a selected permanent data base and to merge these characteristic columns into an intermediate dynamic data base designated, $\left[m_{r_s}\right]$. Therefore

$$\left[m_{r_s}\right] = \left[\left\{M_{s_1}\right\} \vdots \left\{M_{s_2}\right\} \vdots \; - - - \; \vdots \left\{M_{s_{10}}\right\}\right]$$

The reduced size dynamic data base, $\left[m_{r_s}\right]$ thus contains up to ten characteristics for all vehicles or engines in a selected permanent data base. The selected columns

$$j = s_1, s_2, - - -, s_{10}$$

have been chosen by the analyst. Program POWER will subsequently operate on the dynamic data base by performing a correlation-regression analysis in the form

$$W_i = a_i X_1^{b_1} X_2^{b_2} - - - X_N^{b_N}$$

where W_i is a characteristic variable whose sample values are contained in any one of the columns $\left\{m_s\right\}$ selected by the analyst. The X_i are then the characteristic variables whose sample values are contained in the remaining characteristic columns. Program POWER will automatically arrange the X_i

in such a manner that as i increases the characteristic variables, X_i, are of declining statistical significance.

Military Flight Vehicle Data Base, M^1

Characteristic data for 51 military flight vehicles are stored in the M^1 data base. For each vehicle up to 55 geometric or component weight characteristics are stored. Table I presents a list of the vehicles whose characteristics are stored. Table II presents the characteristics which are stored in the military flight vehicle data base. Contents of the military flight vehicle data base can be displayed as previously presented in Figure 4. Volume II of the MARS report lists the complete contents of the military flight vehicle data base. It should be noted that distribution of Volume II is restricted to government personnel and controlled by Advanced Vehicle Concepts Branch, Aeronautics Division, and by Systems Studies Division of NASA's Ames Research Center.

Transport Data Base, M^2

Characteristic data for 40 transport aircraft are stored in the transport data base, M^2. For each vehicle up to 93 geometric or component weight characteristics are stored. Table III presents a list of the vehicles whose characteristics are stored in the transport data base. Table IV presents the characteristics stored in the transport data base. Contents of the transport data base can be displayed by the aircraft as illustrated for the C-130A vehicle in Figure 5. Alternatively the value of a particular characteristic for all aircraft can be displayed in the manner similar to Figure 5. Volume III of the MARS report lists the complete contents of the transport data base. Distribution of Volume III is restricted to government personnel only and controlled by the Aeronautics and System Studies Division of NASA's Ames Research Center.

Turbojet and Turbofan Data Base, M^3

Characteristic data for 35 turbojet and turbofan engines are stored in the data base M^3. For each engine 25 geometric, weight, or operating conditions characteristics are stored. Table V presents a list of the engines whose characteristics are stored in the engine data base. Table VI presents a list of the stored characteristics. Contents of the data base may be displayed by engine as in Figure 6. Alternatively, the value of a given characteristic for all engines can be displayed in a similar manner to Figure 6. Volume IV of the MARS report lists the complete contents of the engine data base. Distribution of Volume IV is restricted to government personnel and is controlled by the Advanced Vehicle Concepts Branch of the Aeronautics Division, NASA's Ames Research Center.

General Aviation Light Aircraft Data Base, M^4

Characteristic data for 71 general aviation light aircraft are stored in the data base, M^4. For each vehicle 15 characteristics are stored. Table VII presents a list of vehicles stored in the general aviation light aircraft data base. Table VIII presents the characteristics which are stored.

Contents of the general aviation data base can be displayed by the aircraft as in Figure 5. Alternatively, the value of a given characteristic for all aircraft can be displayed in a similar manner. Volume V of the MARS report lists the complete contents of the general aviation light aircraft data base, M^4. Distribution of this data base and Volume V is unrestricted. Data source is Brent Silver's Ph.D. thesis, Reference 6.

Theoretical Air-to-Surface Data Bases, M^5 and M^6

Characteristic data for more than 100 Air-to-Surface Missiles (ASM) are stored in the ASM data bases, M^5 and M^6. Characteristics are theoretical and were computed by the vehicle design synthesis and trajectory optimization studies of Reference 7. Characteristics contained in the M^5 and M^6 ASM data bases and their displayed output format are presented in Table IX. Distribution of this data base and its contents are controlled by the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base.

COMPUTATIONAL SEQUENCE

The program first forms the vector of weighted characteristic variable sums

$$P_i = \sum_{i=1}^{M} W_i X_i$$

and the matrix of weighted characteristic variable cross products and squares sums

$$Q_{i_j} = \sum_{i=1}^{M} \sum_{j=1}^{N} W_i W_j X_i X_j$$

The program then computes the vector of characteristic variable means, $\bar{X}_i$ and the variance-covariance matrix

$$(\mathrm{Var})_i = \sum_{i=1}^{M} W_i^2 (X_i - \bar{X}_i)^2 = \sigma_i^2$$

$$(\mathrm{Cov})_{i_j} = \sum_{i=1}^{M} \sum_{j=1}^{N} W_i W_j (X_i - \bar{X}_i)\ (X_j - \bar{X}_j)$$

From this the program computes the vector characteristic variable standard deviations

$$\sigma_i = \sqrt{(\mathrm{Var})_i}$$

and the matrix of characteristic variable linear correlation coefficients

$$P_{i_j} = \frac{(\mathrm{Cov})_{i_j}}{\sigma_i\ \sigma_j}$$

All the above results are printed unless the print suppression indicator is set. At this point the program enters the multiple stepwise linear regression analysis phase and forms N sets of regression equations in the form

$$Y_r = a_r\, X_1^{b_{1_r}}\, X_2^{b_{2_r}} \ldots\ldots\ldots\ldots X_R^{b_{R_r}}$$

Thus, the first equation is of the form

$$Y_1 = a_1 X_1^{b_{11}}$$

the next is

$$Y_2 = a_2 X_1^{b_{12}} X_2^{b_{22}}$$

This process continues until the r^{th} expression is generated

$$Y_R = a_R X_1^{b_{ir}} X_2^{b_{20}} \ldots\ldots\ldots\ldots X_R^{b_{rr}}$$

The variables X_R are defined in the following manner:

X_R is the most significant remaining independent variable

X_R at the r^{th} regression.

At each regression analysis the following information is provided:

1. Step number, r
2. Variable entering, X_i
3. F level, which is a measure of the remaining variance in results removed by X_i
4. Standard error of Y, an estimate of the standard deviation of Y_r on the observation set
5. Multiple correlation coefficient between the dependent variable and the independent variable used
6. The constant term of the equation a_r
7. A tabulation of the independent variables being used, their regression coefficients, b_{ir}, and the regression coefficient standard errors

After the last step of the regression phase the program prints out the final matrix. In this matrix those rows and columns corresponding to characteristic variables that are in the final regression equation constitute the inverse of the corresponding rows and columns of the correlation matrix. If X_i is an independent variable in the final equation and if X_j is not, then the entry in row i, column j of the final matrix is the normalized regression coefficient of X_i on X_j adjusted for any other variable in the equation; in this case the entry in row j, column i is the negative of the entry in row i, column j. The lower right corner entry is the fraction of the variance contributions and final F levels. The final variance contribution of each independent variable in the final equation is the fraction of the variance of the dependent variable due to that independent variable, but not to any other independent variable in the equation. The final variance contribution of a variable, say X_i, <u>not</u> in the final equation is the fraction of the variance of the dependent variable that is "unexplained," and due to X_i. The final variance contribution of independent variables <u>in</u> the final equation appear with a minus sign.

The program finishes with a detailed evaluation of the regression equations obtained by calculating the dependent variable value produced by substituting each observation of the independent variables in the regression equations of Orders 1, 2, . . ., N. A typical program output is presented in Figure 8.

TYPICAL APPLICATIONS OF THE MARS SYSTEM

MARS offers a rapid method for correlating the characteristics of a multivariate system when a data base containing a sufficiently large system sample has been constructed. Correlations are obtained by multivariate regression analysis operating on the system sample, a subset of the system sample, or a weighted set of system samples. A single computer run carries out the correlation-regression analysis. Typical applications of the MARS system to the data bases M^1 to M^4 which contain:

a) Military Flight Vehicle Characteristics, M^1

b) Transport Aircraft Characteristics, M^2

c) Turbojet and Turbofan Characteristics, M^3

d) General Aviation Light Aircraft Characteristics, M^4

are presented in the remainder of this section.

EXAMPLE 1. Application to Military Flight Vehicle Data Base, M^1

Let an expression for the empty weight of a military flight vehicle (MFV) is required and suppose it is assumed that the MFV empty weight depends on the following characteristics:

X_1 - Ultimate Load Factor

X_2 - Wing Area

X_3 - Wing Aspect Ratio

X_4 - Wing Root Thickness

X_5 - Wing Quarter Chord Sweep

X_6 - Fuselage Maximum Depth

X_7 - Fuselage Length

X_8 - Horizontal Tail

X_9 - Vertical Tail Area

The resulting regression analysis equation expressing the dependent variable

$$Y = \text{Empty Weight}$$

will be in the form

$$Y = aX_1^{b_1} X_2^{b_2} \ldots\ldots\ldots\ldots X_9^{b_9}$$

Using the MARS system the following equation is obtained:

$$\begin{aligned} Y = 0.16384 \ & \times (\text{Ultimate Load Factor})^{-.01233} \\ & \times (\text{Wing Area})^{1.2226} \\ & \times (\text{Wing Aspect Ratio})^{.2200} \\ & \times (\text{Wing Root Thickness})^{-.3305} \\ & \times (\text{Wing Quarter Chord Sweep})^{.06188} \\ & \times (\text{Fuselage Maximum Depth})^{-.5819} \\ & \times (\text{Fuselage Length})^{1.0399} \\ & \times (\text{Horizontal Tail Area})^{-.05446} \\ & \times (\text{Vertical Tail Area})^{.07659} \end{aligned}$$

Further the relative statistical significance of the variables X_1 to X_g is found to be:

Variable	Statistical Significance
Ultimate Load Factor	9th
Wing Area	1st
Wing Aspect Ratio	7th
Wing Root Thickness	6th
Wing Quarter Chord Sweep	3rd
Fuselage Maximum Depth	4th
Fuselage Length	2nd
Horizontal Tail Area	8th
Vertical Tail Area	5th

The degree of correlation between predicted and actual weights is illustrated in Figure 9 (a). This figure illustrates typical graphical output from MARS. The diagonal line running from lower left to upper right corners is the line of perfect agreement. Dotted lines above and below the diagonal define the region in which computed empty weight lies within ± 10% of the actual weight. In the lower of the two triangular regions the computed weight is less than the actual weight, or conversely, the actual weight is heavier then the computed weight. Therefore, vehicle predicted empty weights in the lower triangular region indicate a heavier then average aircraft. Similarly, when the predicted empty weight is in the upper triangular region an aircraft is lighter then average.

In the example of Figure 9 (a) only two vehicle empty weight predictions are in error by more then 10%. These aircraft are the McDonnell F101B and F101C. The MARS graphic output can automatically indicate which sample points are employed or which sample points lie outside the 10% scatter band. The latter option has been exercised to replot the results as Figure 9 (b) where the two heavier then average aircraft are indicated by their positions in the MFV data base of Table I.

Figures 9 (c) to 9 (k) present similar correlation-regression analyses where empty weight is separately correlated against each of the characteristic variables employed in the regression analysis.

EXAMPLE 2. Empty Weight of Subsonic Transport Aircraft

Figure 10(a) illustrates a similar study to determine an expression for the empty weight of transport aircraft. Figures 10(b) to 10(j) show the best single variable correlation for the characteristic variable set selected. The same characteristic variable set used in Example 1 is used. The final computer output for this problem was previously given in Figure 8. It can be seen that

$$W_T = 9.46\ L_B^{.587}\ S_W^{.308}\ D_B^{.264}\ \Lambda^{.037}\ S_H^{.287}\ T_R^{-.335}\ S_V^{.143}\ N^{.155}\ AR^{-.111}$$

Note that the equation predicts that empty weight will fall with decreasing root thickness. This statistical anomaly reveals that thin wings have been more carefully (and expensively) designed than thicker wings rather than a true weight sensitivity to root thickness. This type of behavior is frequently encountered in "blind" statistical analysis. The example illustrates the need for careful selection of correlation variables and the need for continual review of the resulting estimation equations. There is also a need to have the ability to bound the variation of the coefficients to prevent such an anomaly. This last capability is now being added to MARS.

EXAMPLE 3. Engine Weight and Length Predictions

In Example 3 turbojet and turbofan weight and length is correlated against:

1. Number of Turbine Stages
2. Number of Compressor Stages
3. Bypass Ratio
4. Turbine Inlet Temperature
5. Thrust at S.L.
6. Engine Diameter
7. Installation Year

In Figure 11(a) the weight correlation is presented. Figure 11(b) shows the weight correlation if length is also made available as a variable. A plot of engine weight vs. length in Figure 11(c) illustrates a MARS feature, the ability to plot a scatter diagram of relating any two variables in the analysis. Separate weight correlations for each variable are presented in Figures 11(d) to 11(k). The MARS system can be used to correlate geometric characteristics as readily as weight or component weight characteristics. This is illustrated by Figure 12 where a set of correlations for engine length are presented. Variables which do not affect length are readily identified and may be removed in subsequent analyses.

EXAMPLE 4. Improving the Correlation by Definition of Reduced Observation Subsets

The engine weight predictions of Example 4 are re-analyzed by grouping the engines into various subsets as follows:

1. Afterburners
2. Non-afterburners
3. Light Engines
4. Heavy Engines
5. Turbojets
6. Turbofans

Results are presented in Figures 13(a) to 13(f). It can be seen that engine weight predictions based on samples which contain "similar" engines in the above grouping significantly improves the estimation. However, as noted previously care must be taken to ensure that this effect is not the sole result of a reduced sample size. Equations obtained in examples 3 and 4 are summarized in Table X.

EXAMPLE 5. A Geometric Correlation, Fighter Horizontal Tail Area

This final example, Figure 14, correlates fighter tail area with the eight parameters:

1. Gross Weight
2. Design Load Factor
3. Wing Area
4. Wing Span
5. Wing Root Thickness
6. Quarter Chord Sweep
7. Fuselage Length
8. Fuselage Depth

It is included as another demonstration of the manner in which vehcile geometric characteristics can be correlated by MARS. This example also illustrates typical output from the TEKTRONIX graphic terminal.

CONCLUSION

The MARS system has been outlined. Data base contents have been described in detail short of the numerical values which they contain. These numerical values are available in Volumes II to V of the present report. However, distribution of Volumes II to V have restricted distributions as noted above. The correlation-regression analysis and graphical display programs have been briefly described. Operation of the MARS system has been illustrated by several examples which are of an illustrative nature only. MARS is an operational system at the present time and has been in use for over one year.

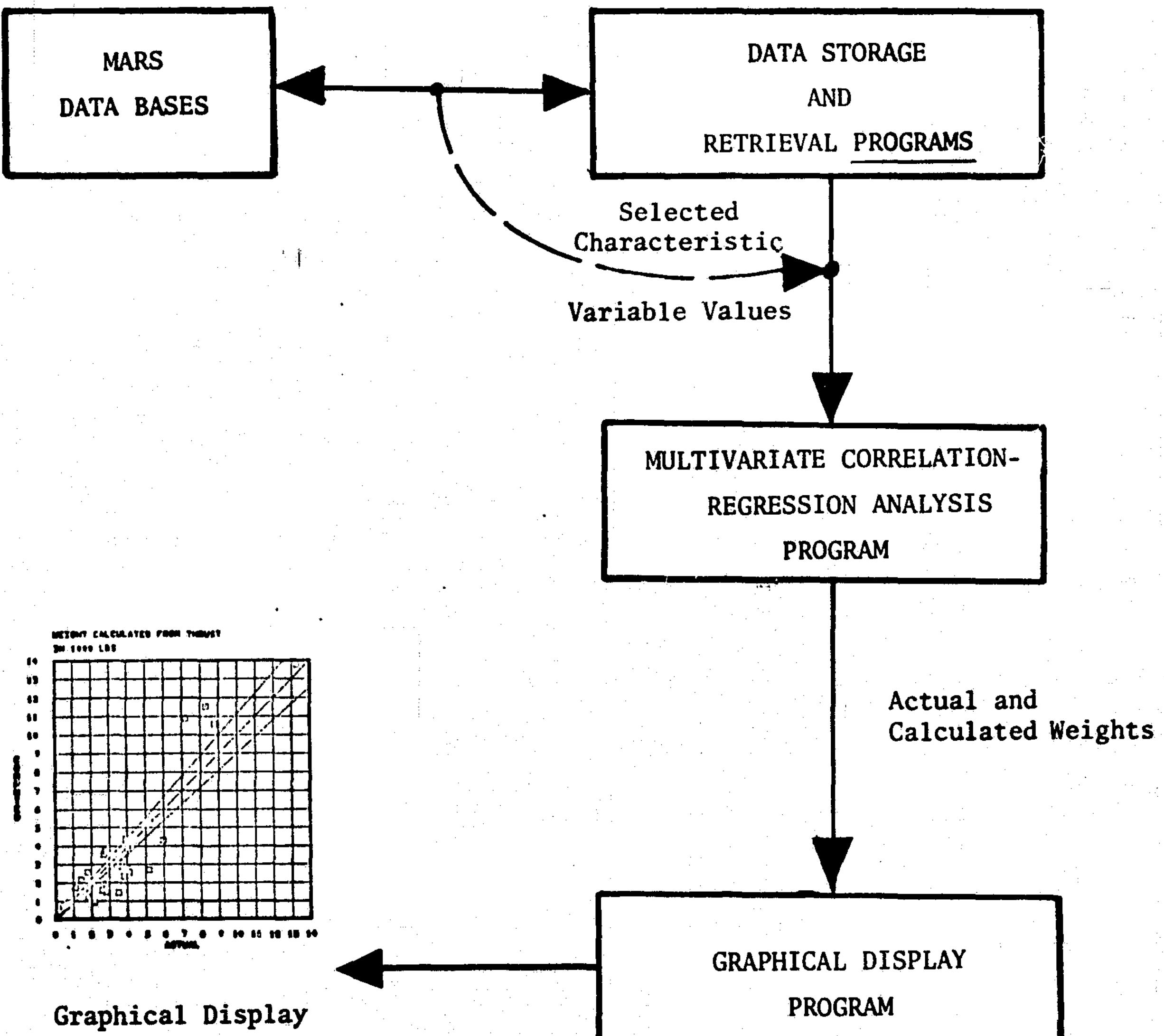

FIGURE 1. MARS SYSTEM SCHEMATIC DIAGRAM

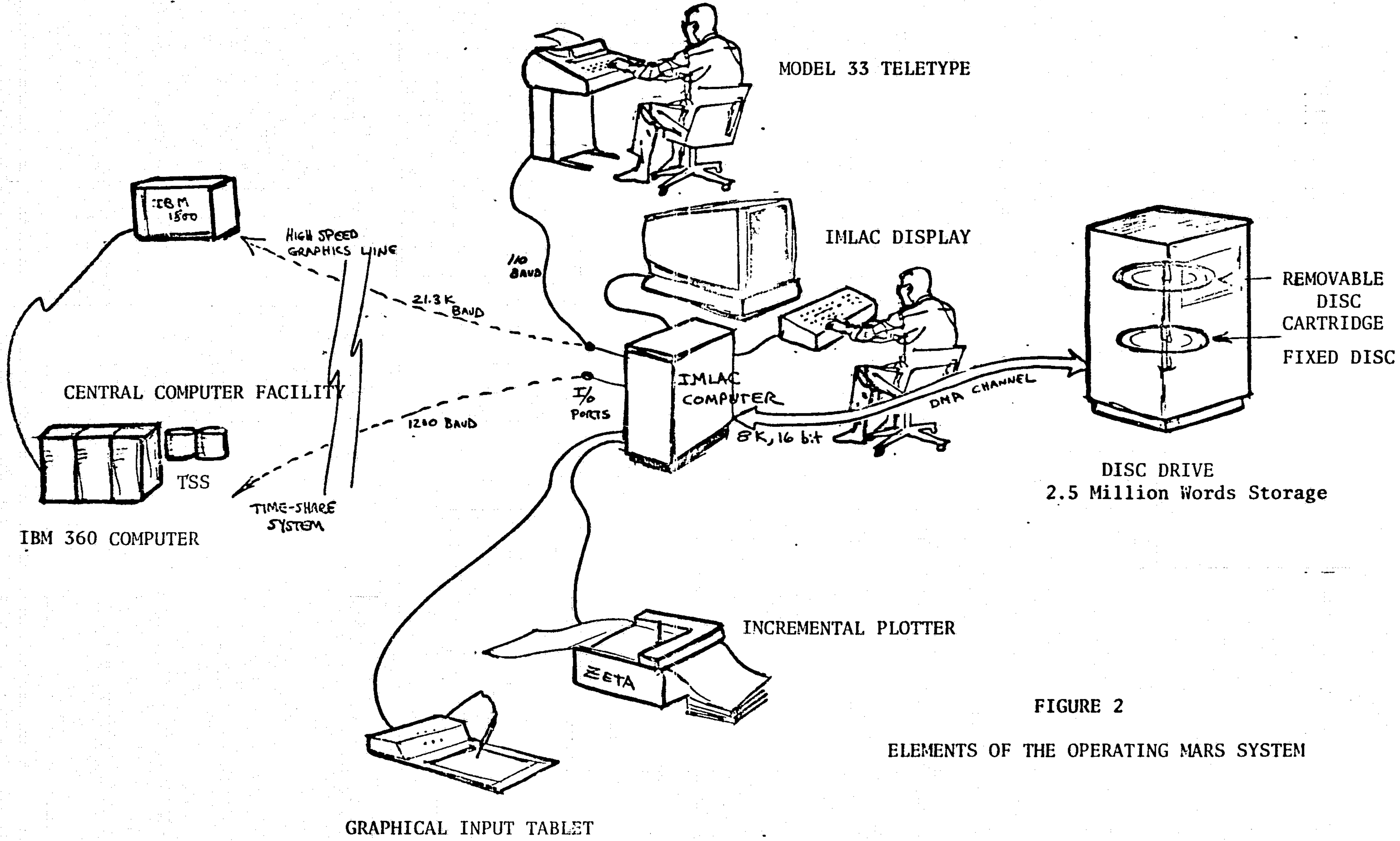

FIGURE 2

ELEMENTS OF THE OPERATING MARS SYSTEM

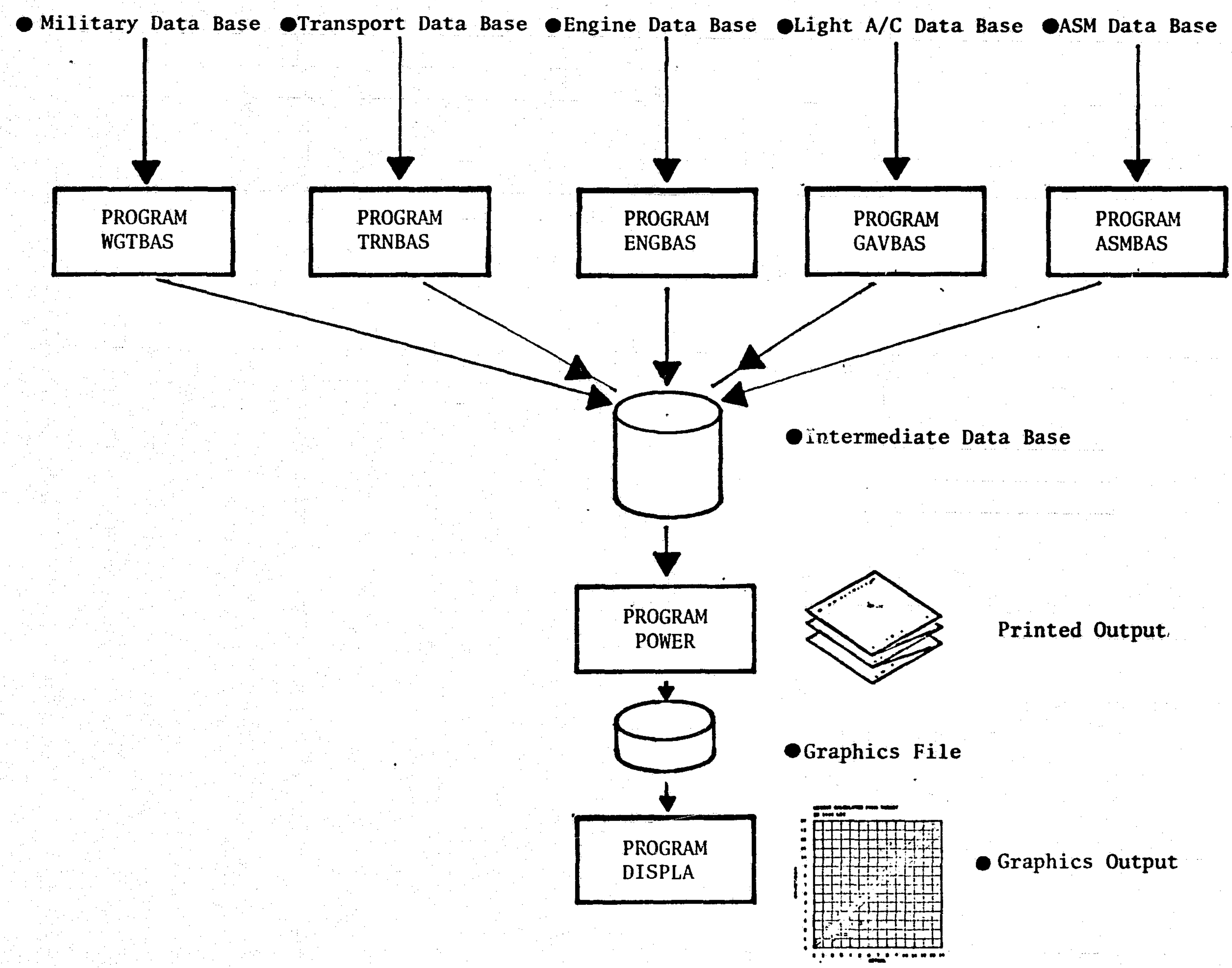

FIGURE 3. SCHEMATIC OF MARS PROGRAM OPERATIONS

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VEHICLE IDENTIFICATION  F-4E-1          PAGE 115

DESIGN GROSS WEIGHT , POUNDS          =    37500.
ULTIMATE LOAD FACTOR, G.              =    12.750
WING AREA,FT**2                       =    538.30
WING ASPECT RATIO                     =    2.7390
WING SPAN, FEET                       =    38.400
T/C AT ROOT                           =   0.63800E-01
T/C AT TIP                            =   0.27100E-01
TIP CHORD/ROOT CHORD                  =    1.3666
COSINE(WING .25 CHORD LINE)           =    45.000
FUSELAGE LENGTH, FEET                 =    51.800
FUSELAGE MAX. DEPTH,FT                =    6.3000
FUSELAGE MAX. WIDTH,FT                =    7.8000
TAIL TYPE COSE                        =    1.0000
HORIZONAL TAIL AREA,FT**2             =    96.200
VERTICAL TAIL AREA,FT**2              =    67.500
EMPTY WEIGHT,POUNDS                   =    28541.
SINK SPEED, FT/SECOND                 =    10.000
WING GROUP WEIGHT                     =    4670.0
WING BASIC STRUCTURE WT.              =    3331.0
WING SECONDARY STRUCT. WT.            =    465.00
AILERON WEIGHT                        =   0.11111E-08
L.E. FLAP WEIGHT                      =    404.00
T.E. FLAP WEIGHT                      =    180.00
SLATS WEIGHT                          =   0.11111E-08
SPOILERS WEIGHT                       =    154.00
TAIL GROUP WEIGHT                     =    953.00
STABILIZER WEIGHT                     =    667.00
ELEVATOR WEIGHT                       =   0.11111E-08
FIN WEIGHT                            =    222.00
RUDDER WEIGHT                         =    64.000
BODY GROUP WEIGHT                     =    4919.0
FUSELAGE BASIC STRUCTURE              =    3044.0
LANDING GEAR WEIGHT                   =    1968.0
MAIN LANDING GEAR WEIGHT              =    1592.0
NOSE LANDING GEAR WEIGHT              =    376.00
SURFACE CONTROL GROUP WT.             =    976.00
```

FIGURE 4. F4E WEIGHT SUMMARY FROM DATA BASE M[1]

```
VEHICLE IDENTIFICATION  F-4E-1        PAGE 116

COCKPIT CONTROL WEIGHT                  =   73.000
AUTOPILOT WEIGHT                        =   63.000
SYSTEM CONTROLS WEIGHT                  =   840.00
A.P.U. GROUP      WEIGHT                =  0.11111E-08
INST. + NAVIGATION GROUP WT.            =   256.00
HYD. + PNEUMATIC GROUP WT.              =   523.00
HYDRAULIC SYSTEM WEIGHT                 =  0.11111E-08
PNEUMATIC SYSTEM WEIGHT                 =  0.11111E-08
ELECTRICAL SYSTEM WEIGHT                =   527.00
AVIONICS GROUP WEIGHT                   =   1899.0
AVIONICS EQUIPMENT WEIGHT               =   1414.0
AVIONICS INSTALLATION WEIGHT            =   485.00
FURNITURE GROUP WEIGHT                  =   521.00
PERSONNEL ACCOMMODATIONS WT.            =   391.00
PERSONNEL FUNISHING WEIGHT              =   20.000
MISCELLANEOUS WEIGHT                    =   38.000
EMERGENCY EQUIPMENT WEIGHT              =   22.000
AIR CONDITIONING GROUP WT.              =   399.00
AIR CONDITIONING SYSTEM WT.             =   399.00
DE ICER SYSTEM WEIGHT                   =  0.11111E-08
COMPUTED QUARTER CHORD SPAN             =  0.35333
COMPUTED ROOT CHORD                     =   11.847
COMPUTED ROOT THICKNESS                 =  0.75582
VERTICAL TAIL WEIGHT                    =   286.00
HORIZONTAL TAIL WEIGHT                  =   667.00
COMPUTED BODY AREA                      =   1241.6
COMPUTED NON-BASIC BODY WT.             =   1875.0
APPROX. MAXIMUM PRESSURE                =   999.00
```

FIGURE 4. (cont'd)

```
DESIGN GROSS WEIGHT , POUNDS          =  0.10800E 06

ULTIMATE LOAD FACTOR, G.              =   4.5000

WING AREA,FT**2                       =   1745.0

WING ASPECT RATIO                     =   10.080

WING SPAN, FEET                       =   132.60

T/C AT ROOT                           =  0.17980

T/C AT TIP                            =  0.12000

TIP CHORD/ROOT CHORD                  =  0.52100

COSINE(WING .25 CHORD LINE)           =  0.00000

FUSELAGE LENGTH, FEET                 =   95.750

FUSELAGE MAX. DEPTH,FT                =   13.250

FUSELAGE MAX. WIDTH,FT                =   14.160

TAIL TYPE COSE                        =  0.11111E-08

HORIZONAL TAIL AREA,FT**2             =   545.00

VERTICAL TAIL AREA,FT**2              =   300.00

EMPTY WEIGHT,POUNDS                   =   59162.

SINK SPEED, FT/SECOND                 =  0.11111E-08

WING GROUP WEIGHT                     =   10483.

WING BASIC STRUCTURE WT.              =   8253.0

WING SECONDARY STRUCT. WT.            =   762.00

AILERON WEIGHT                        =   412.00

L.E. FLAP WEIGHT                      =  0.11111E-08

T.E. FLAP WEIGHT                      =   1056.0

SLATS WEIGHT                          =  0.11111E-08

SPOILERS WEIGHT                       =  0.11111E-08

TAIL GROUP WEIGHT                     =   3122.0

STABILIZER WEIGHT                     =   1206.0
```

FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE

```
ELEVATOR WEIGHT                      =    967.00
FIN WEIGHT                           =    845.00
RUDDER WEIGHT                        =    274.00
BODY GROUP WEIGHT                    =    13356.
FUSELAGE BASIC STRUCTURE             =    9701.0
LANDING GEAR WEIGHT                  =    4321.0
MAIN LANDING GEAR WEIGHT             =    4336.0
NOSE LANDING GEAR WEIGHT             =    624.00
SURFACE CONTROL GROUP WT.            =    1480.0
COCKPIT CONTROL WEIGHT               =    106.00
AUTOPILOT WEIGHT                     =    204.00
SYSTEM CONTROLS WEIGHT               =    1170.0
A.P.U. GROUP      WEIGHT             =    411.00
INST. + NAVIGATION GROUP WT.         =    613.00
HYD. + PNEUMATIC GROUP WT.           =    667.00
HYDRAULIC SYSTEM WEIGHT              =  0.11111E-08
PNEUMATIC SYSTEM WEIGHT              =  0.11111E-08
ELECTRICAL SYSTEM WEIGHT             =    1865.0
AVIONICS GROUP WEIGHT                =    1850.0
AVIONICS EQUIPMENT WEIGHT            =    1266.0
AVIONICS INSTALLATION WEIGHT         =    584.00
FURNITURE GROUP WEIGHT               =    3259.0
PERSONNEL ACCOMMODATIONS WT.         =    1680.0
PERSONNEL FUNISHING WEIGHT           =    484.00
MISCELLANEOUS WEIGHT                 =    669.00
EMERGENCY EQUIPMENT WEIGHT           =    426.00
AIR CONDITIONING GROUP WT.           =    2257.0
```

FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE (cont'd)

AIR CONDITIONING SYSTEM WT. = 1316.0

DE ICER SYSTEM WEIGHT = 941.00

NUMBER IN CREW = 4.0000

NUMBER OF STEWARDESSES = 0.11111E-08

NO. OF 1ST CLASS PASSENGERS = 0.11111E-08

NO. OF TOURIST PASSENGERS = 0.11111E-08

AILERON AREA = 110.00

LEADING EDGE FLAP AREA = 0.11111E-08

TRAILING EDGE FLAP AREA = 342.00

SLAT AREA = 0.11111E-08

SPOILER AREA = 0.11111E-08

STABILIZER AREA = 0.11111E-08

ELEVATOR AREA = 0.11111E-08

FIN AREA = 0.11111E-08

RUDDER AREA = 0.11111E-06

NUMBER OF ENGINES = 4.0000

ENGINE MAKE = 0.11111E-08

ENGINE THRUST = 0.11111E-08

NACELLE GROUP WEIGHT = 2720.0

INBOARD NACELLE WEIGHT = 1274.0

OUTBOARD NACELLE WEIGHT = 1273.0

FUSELAGE WETTED AREA = 3460.0

INBOARD NACELLE LENGTH = 19.500

INBOARD NACELLE DEPTH = 5.0000

INBOARD NACELLE WIDTH = 3.1700

OUTBOARD NACELLE LENGTH = 20.400

OUTBOARD NACELLE DEPTH = 5.0000

ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE (cont'd)

```
V E H I C L E   I D E N T I F I C A T I O N   C-130A          PAGE  12

OUTBOARD NACELLE WIDTH                     =    3.1700

TOTAL AILERON AREA                         =  0.11111E-08

TOTAL L.E. FLAP AREA                       =  0.11111E-08

TOTAL T.E. FLAP AREA                       =  0.11111E-08

TOTAL SLAT AREA                            =  0.11111E-08

TOTAL SPOILER AREA                         =  0.11111E-08

MAXIMUM DYNAMIC PRESSURE                   =    300.00

ALTITUDE FOR MAXIMUM G                     =    10000.

MAXIMUM MACH NUMBER                        =   0.54000

CRUISE SPEED IN MACH NUMBER                =   0.50000

CRUISE SPEED IN MPH                        =    360.00

CRUISE ALTITUDE                            =    10000.
```

FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE (cont'd)

```
E N G I N E   I D E N T I F I C A T I O N   T39A     ENGINE NO. = 26

BYPASS RATIO                                  =  0.00000

OVERALL COMPRESSOR PRESS. RATIO               =   7.0000

OUTER   COMPRESSOR PRESS. RATIO               =   1.0000

NO. OF STAGES, LOW PRESS.COMPRESSOR           =  0.00000

NO. OF STAGES, HIGH PRESS.COMPRESSOR          =   9.0000

NO. OF STAGES, LOW PRESS.TURBINE              =  0.00000

NO. OF STAGES, HIGHPRESS.TURBINE              =   2.0000

FAN PRESSURE RATIO                            =   1.0000

TURBINE MAX. INLET TEMP. DEGREES F            =   1600.0

NOMINAL ENGINE LENGTH , INCHES                =   79.500

WEIGHT IN POUNDS                              =   460.00

S.L. STATIC MIL. POWER(30 MIN. MAX.)          =   3000.0

S.L. S F C  MIL. POWER(30 MIN. MAX.)          =  0.96000

ENGINE MASS FLOW S.L. STATIC, LBS/SEC         =   50.000

S.L. STATIC MAX. A/B THRUST                   =  -1.0000

S.L. STATIC MAX. A/B S.F.C.                   =  -1.0000

NOMINAL ENGINE DIAMETER, INCHES               =   23.400

                                              =  0.11111E-08

INSTALLATION MONTH                            =   10.000

INSTALLATION YEAR                             =   60.000

TOTAL NUMBER OF COMP. STAGES                  =   9.0000

TOTAL NUMBER OF TURBINE STAGES                =   2.0000

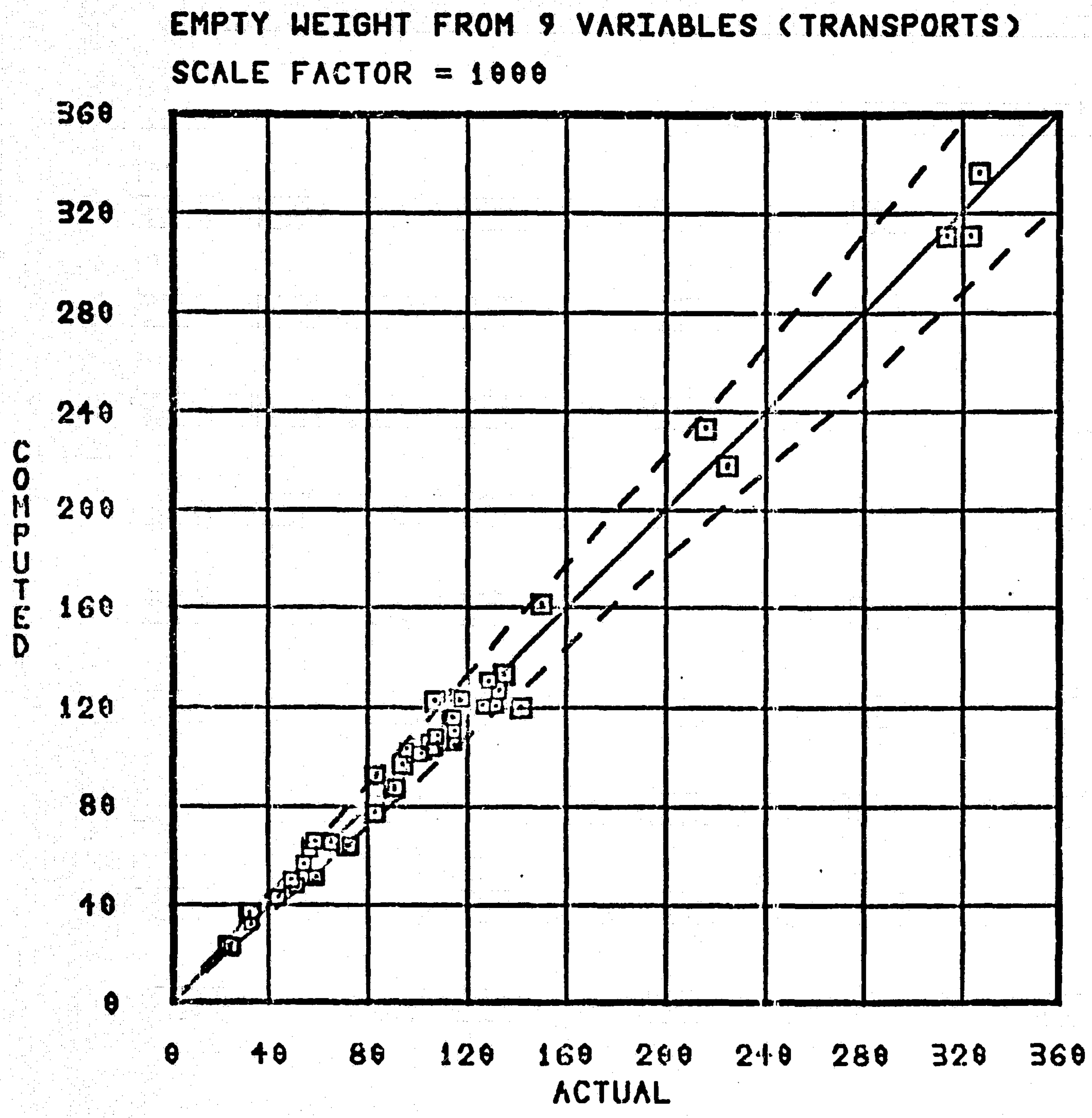
A/B THRUST TO NON A/B THRUST RATIO            =   1.0000

BYPASS RATIO + 1                              =   1.0000

THRUST/WEIGHT                                 =   6.5217

THRUST PER SQUARE INCH                        =   6.9759
```

FIGURE 6. CHARACTERISTICS OF J60-P-3 ENGINE FROM ENGINE DATA BASE



PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
2	L-188
6	HC-130H
18	DC-8-10
23	F-2B
32	VC-10

FIGURE 7. TYPICAL GRAPHICAL OUTPUT

```
EXPRESSION FOR:  EMPTY WEIGHT,POUNDS
ORDER OF REGRESSION =     9
CONSTANT MULTIPLIER, A= 0.94629E 01

EXPONENTIAL CONSTANTS                         VARIABLE
      0.598551                      FUSELAGE LENGTH, FEET
      0.237910                      WING AREA,FT**2
      0.264151                      FUSELAGE MAX. DEPTH,FT
      0.236657                      COS(SWEEP(WING .25 CHORD LINE)
      0.286543                      HORIZONAL TAIL AREA,FT**2
     -0.334586                      T/C AT ROOT
      0.142569                      VERTICAL TAIL AREA,FT**2
      0.154253                      ULTIMATE LOAD FACTOR, G.
     -0.111265                      WING ASPECT RATIO

SAMPLE NO.    VEHICLE ID.   INPUT VALUE   CALCULATED VALUE      DIFF.             RATIO
     1          F-27         23575.000      0.23485E 05    -0.90586E 02         -0.38 %
     2          L-188        58012.031      0.51948E 05    -0.60636E 04        -10.45 %
     3          C-130A       59162.027      0.64676E 05     0.55135E 04          9.32 %
     4          C-130A       57407.027      0.62740E 05     0.53327E 04          9.29 %
     5          C-130B       67574.063      0.64676E 05    -0.29021E 04         -4.29 %
     6          HC-130H      72038.063      0.64368E 05    -0.76705E 04        -10.65 %
     7          C-133A      116810.063      0.12322E 06     0.64079E 04          5.49 %
     8          C-133A      113810.063      0.11578E 06     0.17664E 04          1.73 %
     9          SE210-6N     58455.023      0.61617E 05     0.31513E 04          5.39 %
    10          707-120     108340.000      0.10675E 06    -0.15906E 04         -1.47 %
    11          707-020     101600.000      0.10294E 06     0.13444E 04          1.32 %
    12          707-320     122600.000      0.12479E 06     0.21927E 04          1.79 %
    13          707-320B    131560.125      0.12634E 06    -0.52212E 04         -3.97 %
    14          720         101630.063      0.10336E 06     0.17309E 04          1.70 %
    15          C-135A       99359.063      0.10224E 06     0.28768E 04          2.90 %
    16          KC-135A      94100.063      0.97150E 05     0.30501E 04          3.24 %
    17          C-135B      105800.063      0.10480E 06    -0.10045E 04         -0.95 %
    18          DC-8-10     106900.000      0.12273E 06     0.15831E 05         14.82 %
    19          DC-8F-54    129160.000      0.12995E 06     0.78963E 03          0.61 %
    20          DC-8-62     134620.125      0.13301E 06    -0.16070E 04         -1.19 %
    21          880          83014.063      0.92187E 05     0.91722E 04         11.05 %
    22          990         113520.125      0.10691E 06    -0.66118E 04         -5.82 %
    23          F-28         31887.016      0.36269E 05     0.43808E 04         13.74 %
    24          DC-9-10      47890.027      0.47511E 05    -0.37917E 03         -0.76 %
    25          DC-9-30      55269.012      0.53266E 05    -0.20033E 04         -3.62 %


SAMPLE NO.    VEHICLE ID.   INPUT VALUE   CALCULATED VALUE      DIFF.             RATIO
    26          DC-9-30      55950.004      0.53266E 05    -0.26843E 04         -4.80 %
    27          727-100      82797.000      0.77252E 05    -0.55454E 04         -6.70 %
    28          727-200      90900.063      0.87719E 05    -0.31824E 04         -3.50 %
    29          737-100      53800.023      0.52323E 05    -0.14768E 04         -2.75 %
    31          737-200      54828.027      0.56296E 05     0.14684E 04          2.68 %
    32          VC-10       141690.125      0.12014E 06    -0.21532E 05        -15.20 %
    33          VC-10S      149800.125      0.16165E 06     0.11852E 05          7.91 %
    34          G141-2      130360.125      0.12167E 06    -0.86940E 04         -6.67 %
    35          C-5A        327000.125      0.33545E 06     0.84514E 04          2.58 %
    36          DC-10-10    224470.125      0.21818E 06    -0.62934E 04         -2.80 %
    37          747-27      323070.250      0.31061E 06    -0.12463E 05         -3.86 %
    38          747F        313210.188      0.31061E 06    -0.26076E 04         -0.83 %
    39          L1011       215990.063      0.23289E 06     0.16904E 05          7.83 %
    40          C-141-1     127640.063      0.12167E 06    -0.59739E 04         -4.68 %
```

FIGURE 8. TYPICAL REGRESSION ANALYSIS FINAL OUTPUT

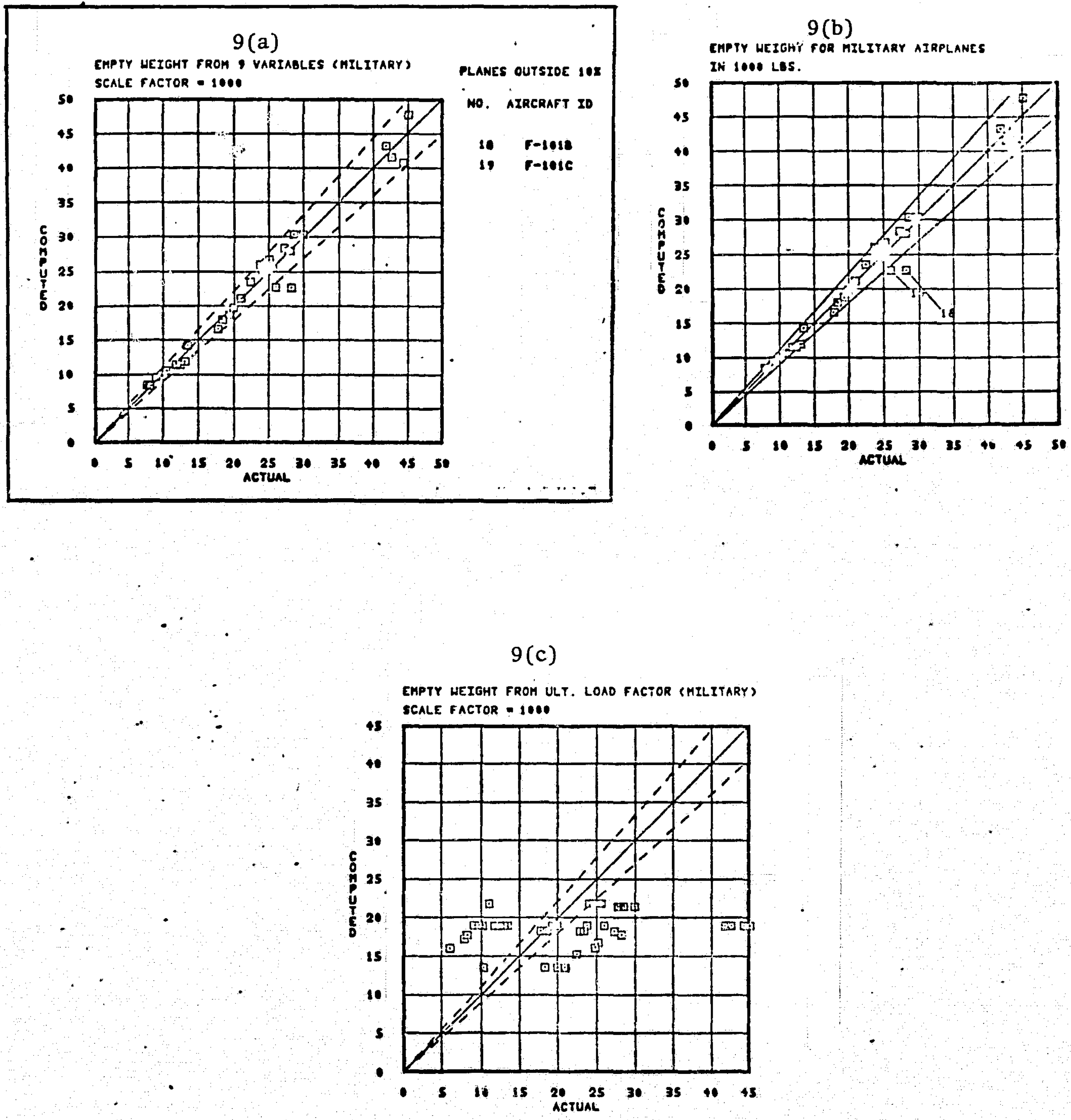
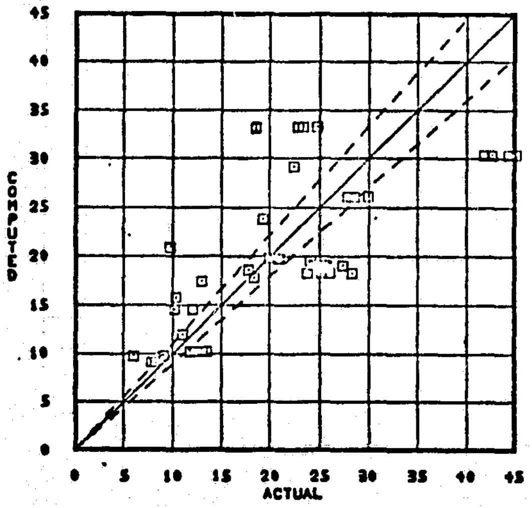


FIGURE 9. MILITARY AIRCRAFT

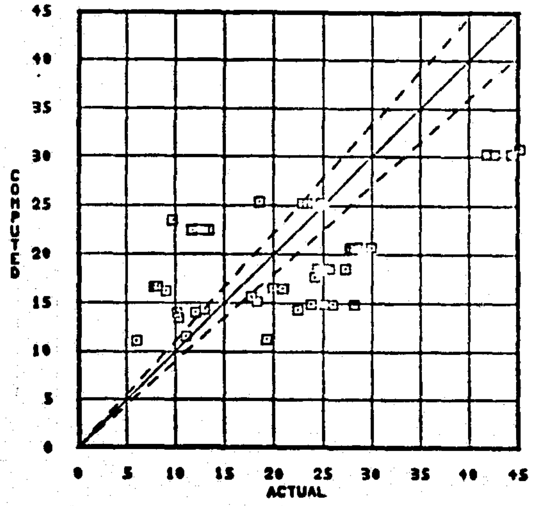
9(d)

EMPTY WEIGHT FROM WING AREA (MILITARY)
SCALE FACTOR = 1000



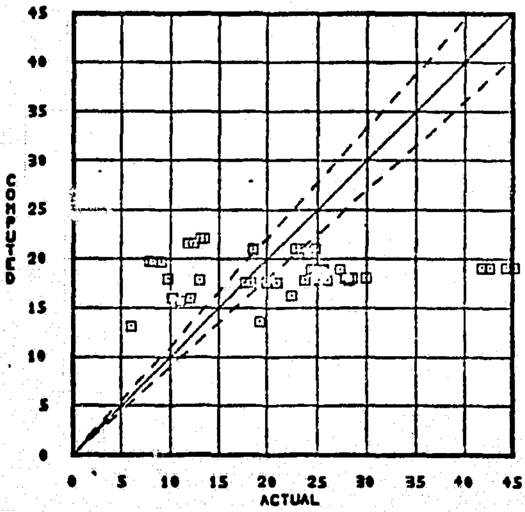
9(e)

EMPTY WEIGHT FROM ASPECT RATIO (MILITARY)
SCALE FACTOR = 1000



9(f)

EMPTY WEIGHT FROM T/C AT ROOT (MILITARY)
SCALE FACTOR = 1000



9(g)

EMPTY WEIGHT FROM COS(WING .25 CHORD)
SCALE FACTOR = 1000

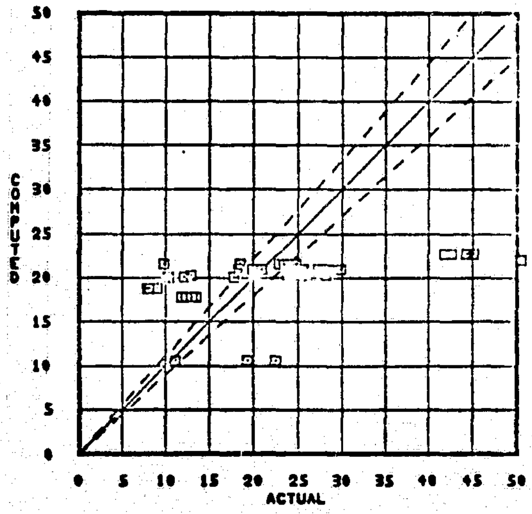
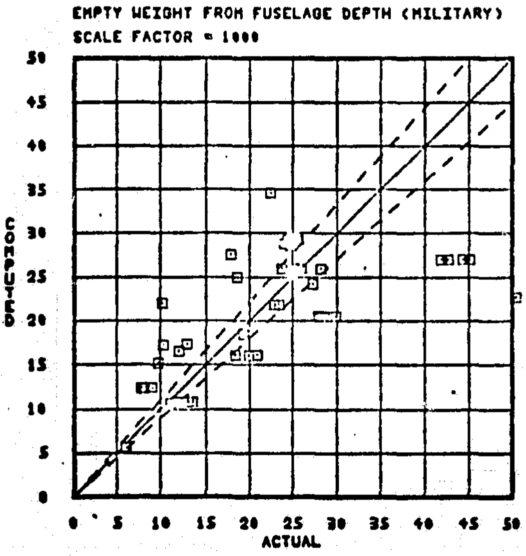
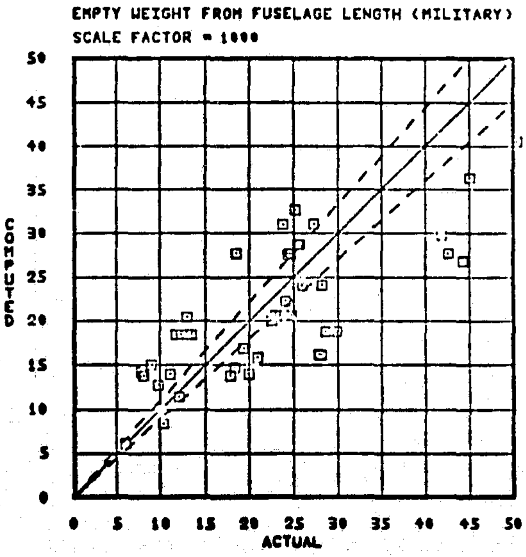


FIGURE 9. MILITARY AIRCRAFT (cont'd)

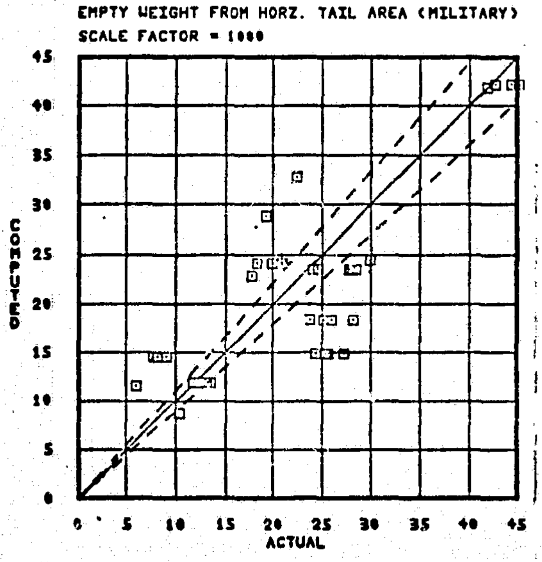
9(h)



9(i)



9(j)



9(k)

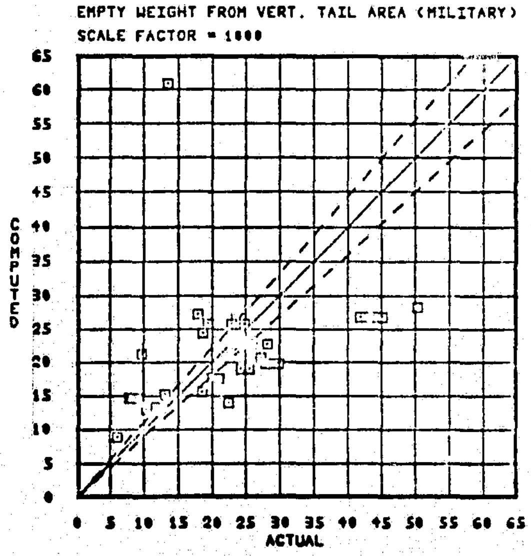
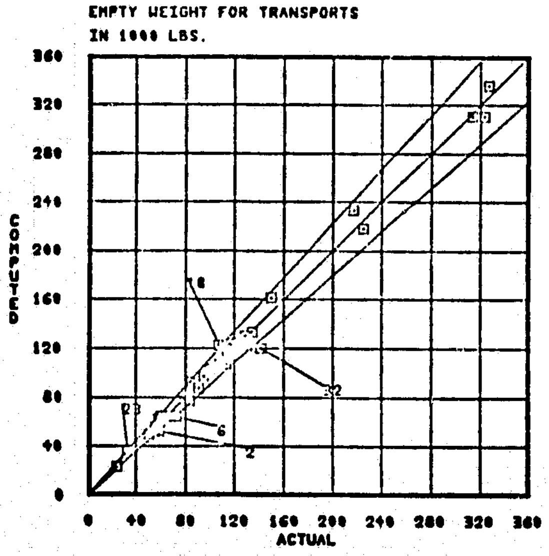


FIGURE 9. MILITARY AIRCRAFT (cont'd)

10(a)



10(b)

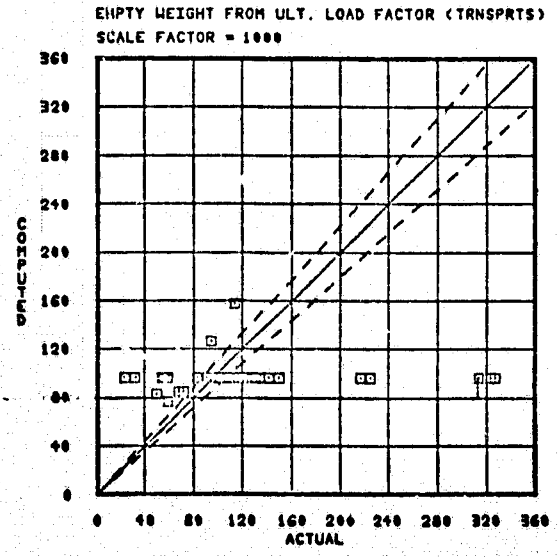
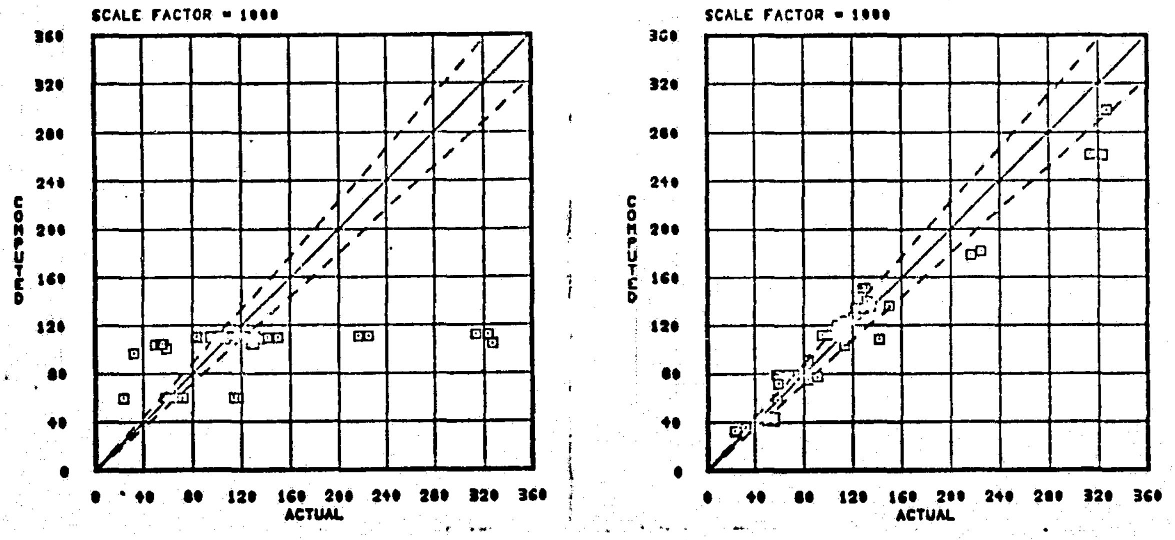


FIGURE 10. TRANSPORT AIRCRAFT

10(c) 10(d)



10(e) 10(f)

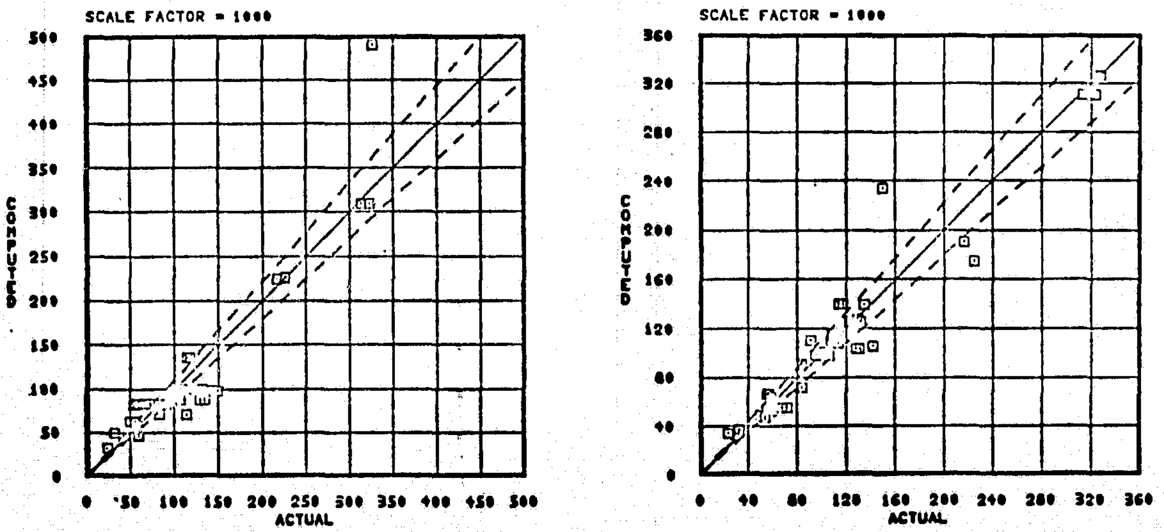
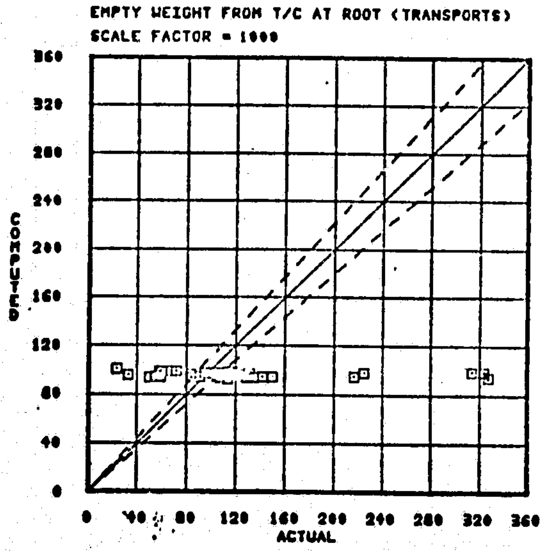
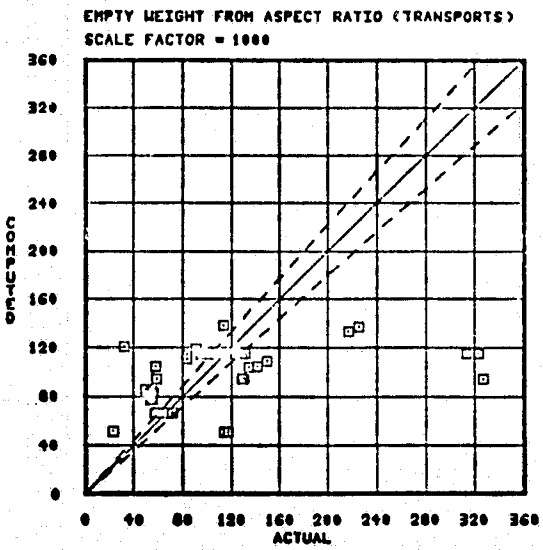


FIGURE 10. TRANSPORT AIRCRAFT (cont'd)

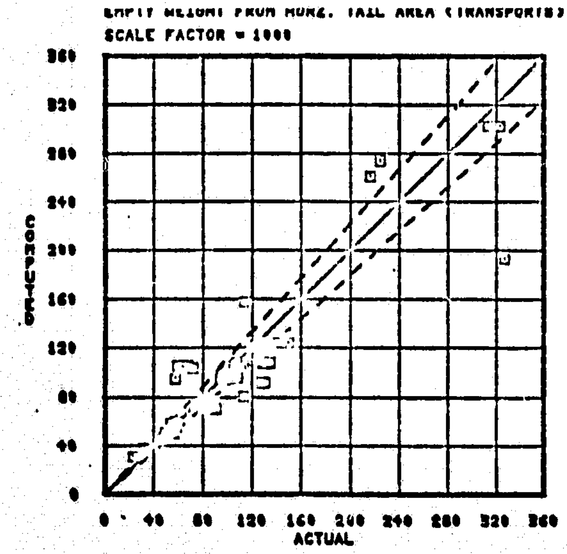
10(g)



10(h)



10(i)



10(j)

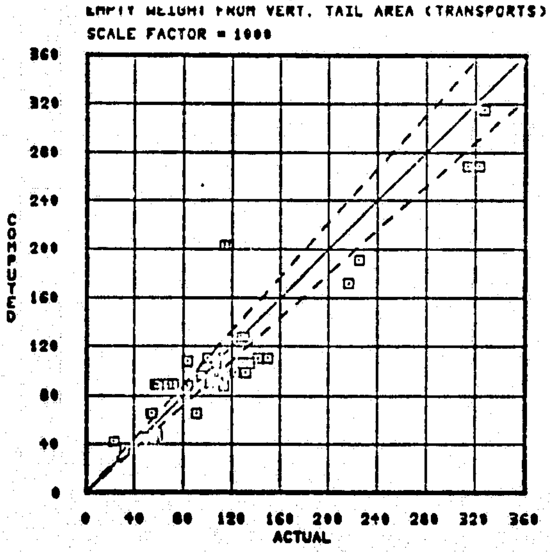


FIGURE 10. TRANSPORT AIRCRAFT (cont'd)

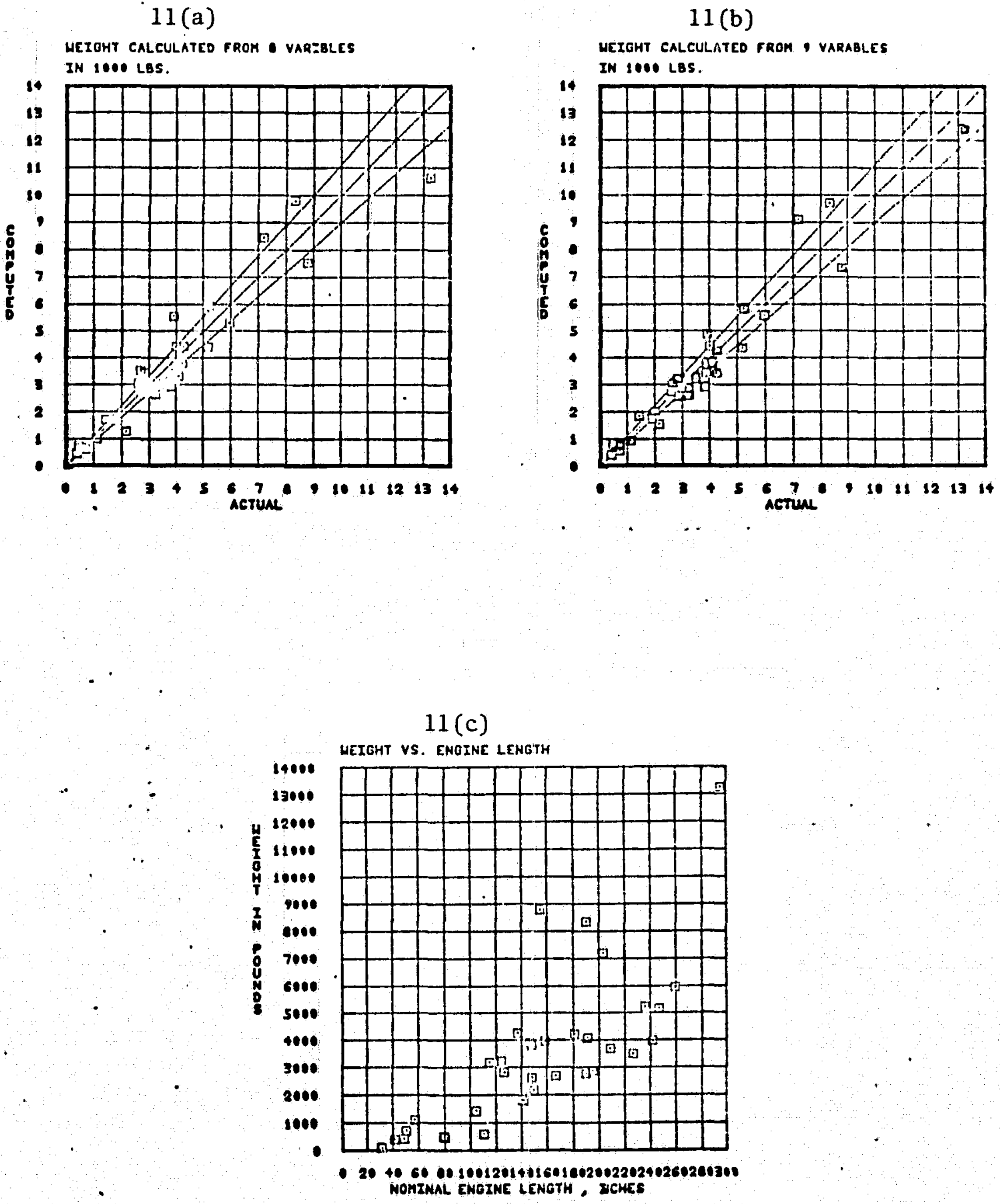
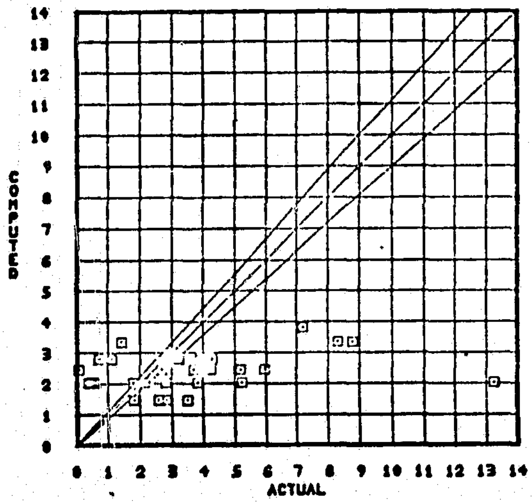


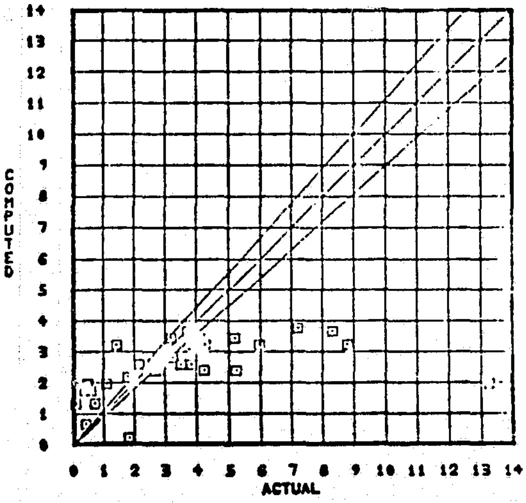
FIGURE 11. TURBOJET & TURBOFAN ENGINES

11(d)



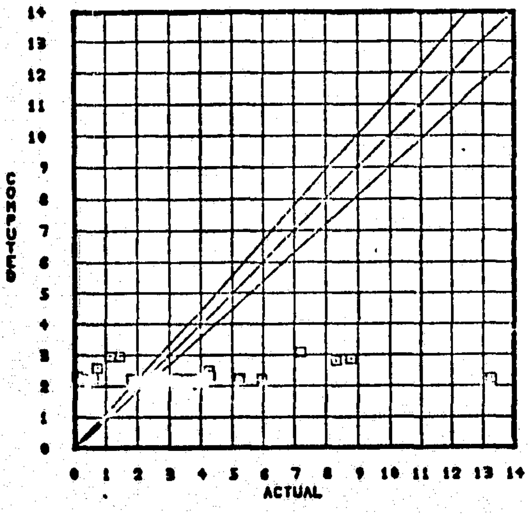
WEIGHT CALCULATED FROM NUMBER OF TURBINE STAGES
IN 1000 LBS.

11(e)



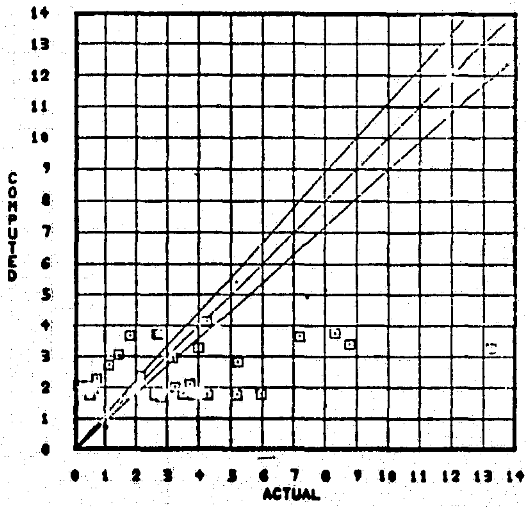
WEIGHT CALCULATED FROM NUMBER OF COMPRESSOR STAGES
IN 1000 LBS.

11(f)



WEIGHT CALCULATED FROM THE BYPASS RATIO
IN 1000 LBS.

11(g)

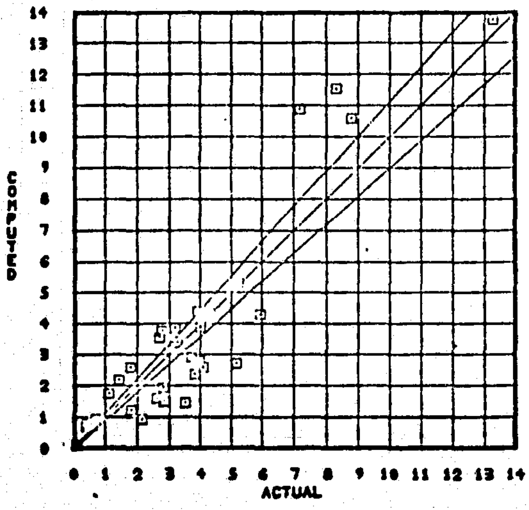


WEIGHT CALCULATED FROM INLET TEMPERATURE
IN 1000 LBS.

FIGURE 11. TURBOJET & TURBOFAN ENGINES (cont'd)

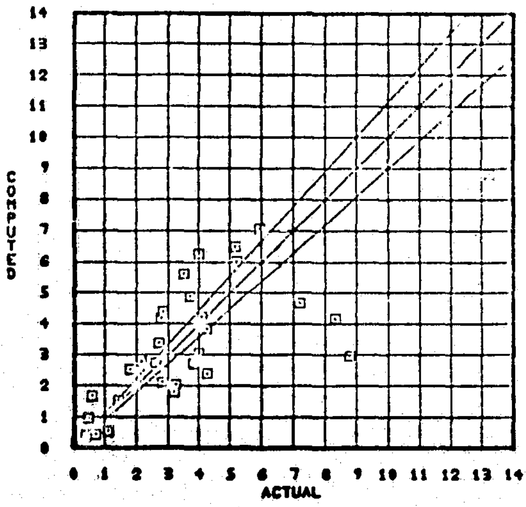
11(h)

WEIGHT CALCULATED FROM THRUST
IN 1000 LBS.



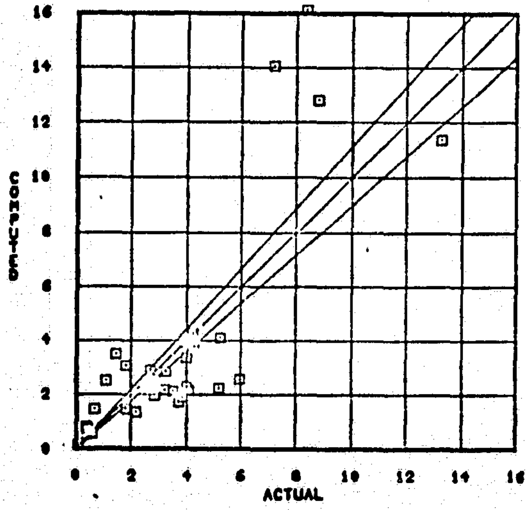
11(i)

WEIGHT CALCULATED FROM ENGINE LENGTH
IN 1000 LBS.



11(j)

WEIGHT CALCULATED FROM ENGINE DIAMETER
IN 1000 LBS.



11(k)

WEIGHT CALCULATED FROM INSTALLATION YEAR
IN 1000 LBS.

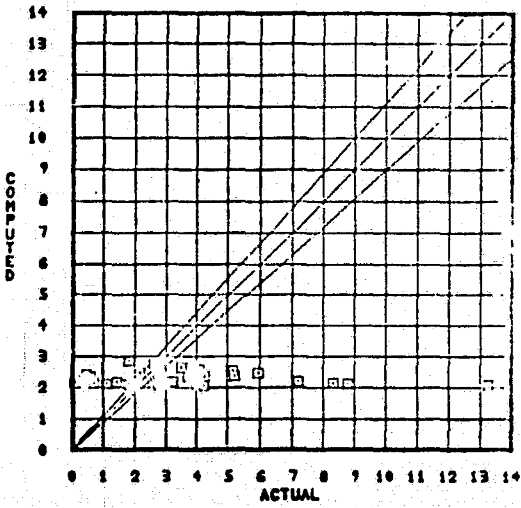
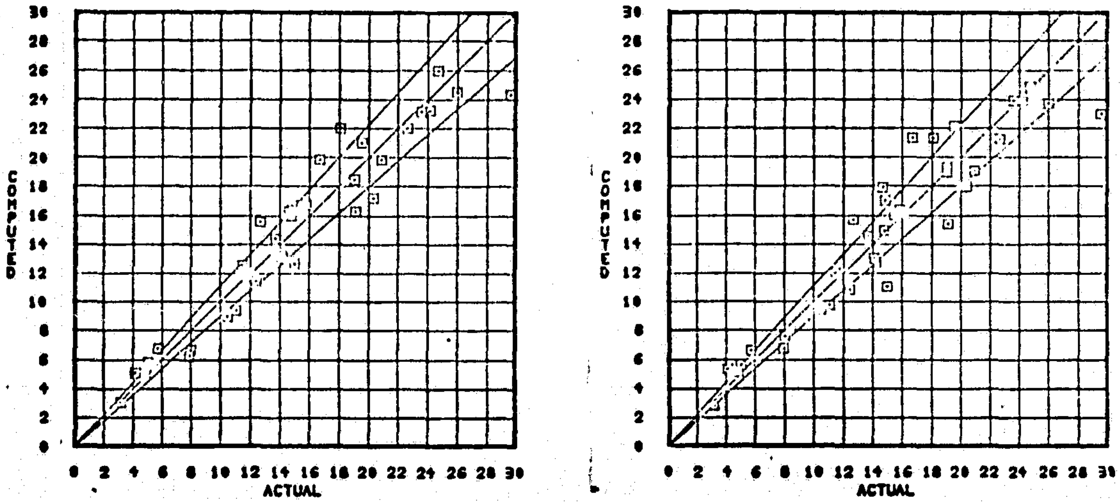
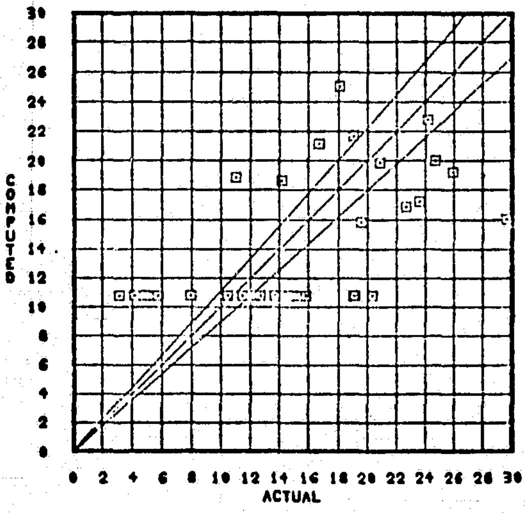


FIGURE 11. TURBOJET & TURBOFAN ENGINES (cont'd)



12(a)
ENGINE LENGTH CALCULATED FROM 9 VARIBLES

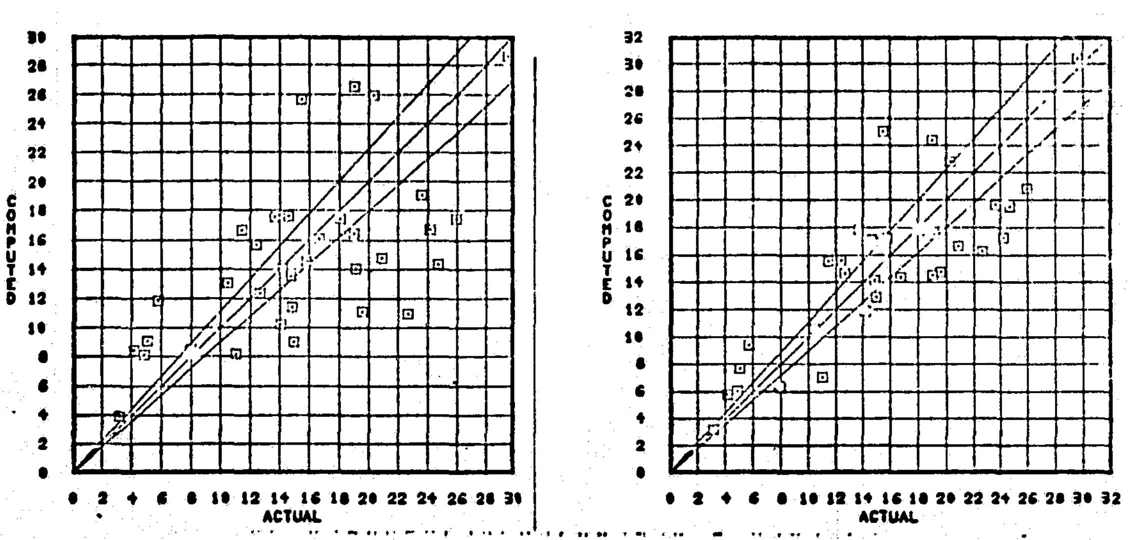
12(b)
ENGINE LENGTH CALCULATED FROM 8 VARIBLES



12(c)
ENGINE LENGTH CALCULATED FROM THE THRUST RATIO

FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION

12(d) 12(e)



12(f) 12(g)

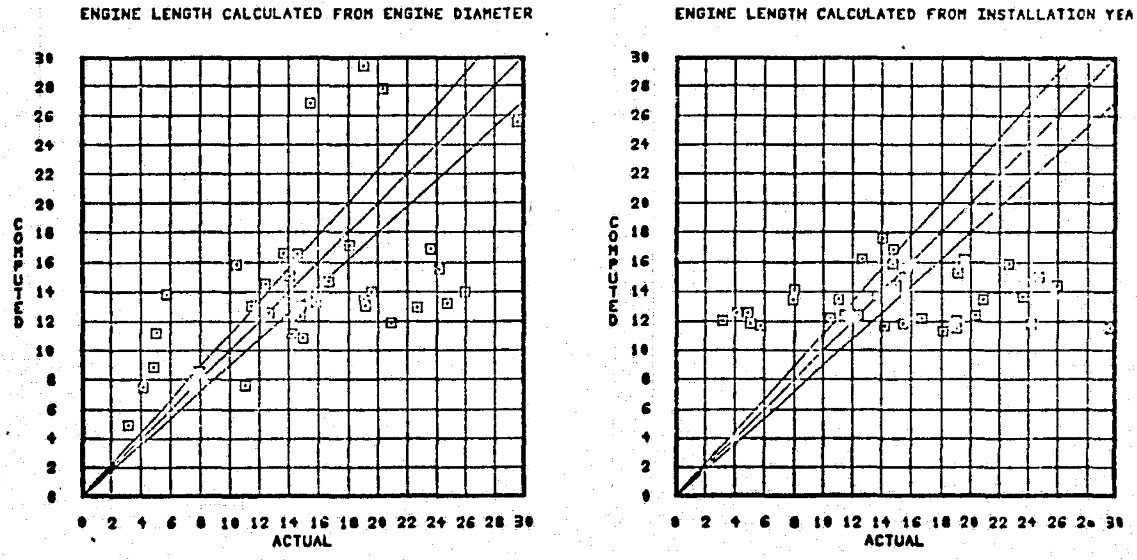
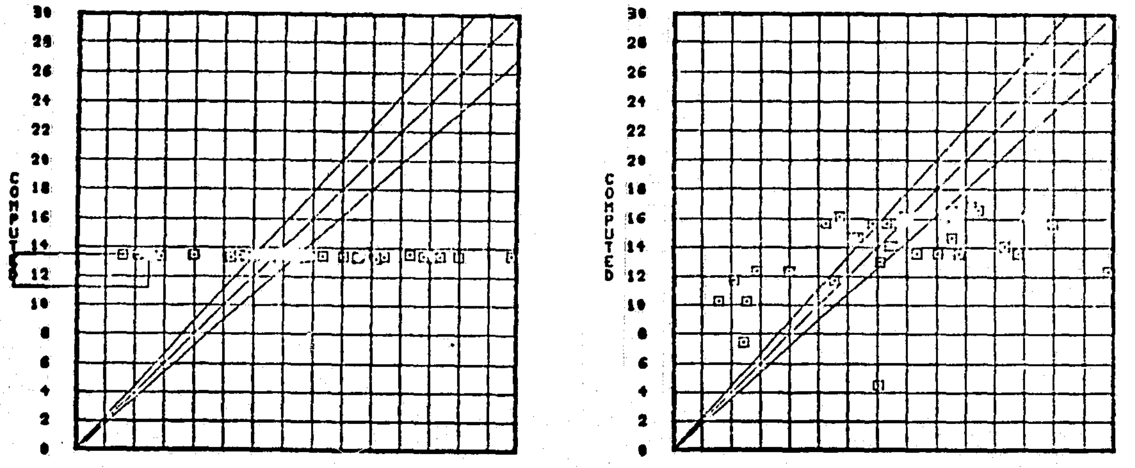


FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION (cont'd)

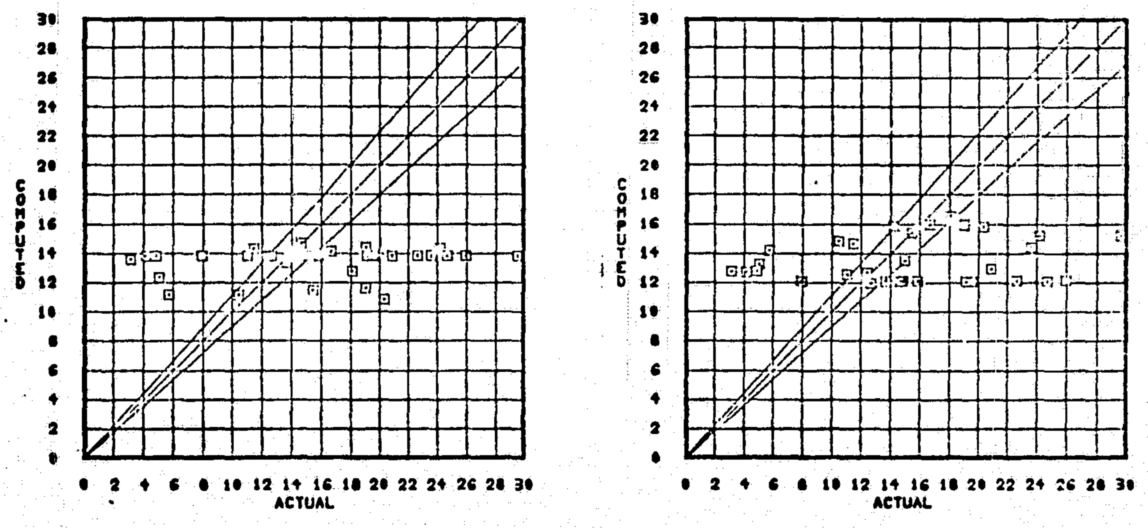


12(h)

ENGINE LENGTH FROM NUMBER OF TURBINE STAGES

12(i)

ENGINE LENGTH FROM NUMBER OF COMPRESSOR STAGES



12(j)

ENGINE LENGTH CALCULATED FROM THE BYPASS RATIO

12(k)

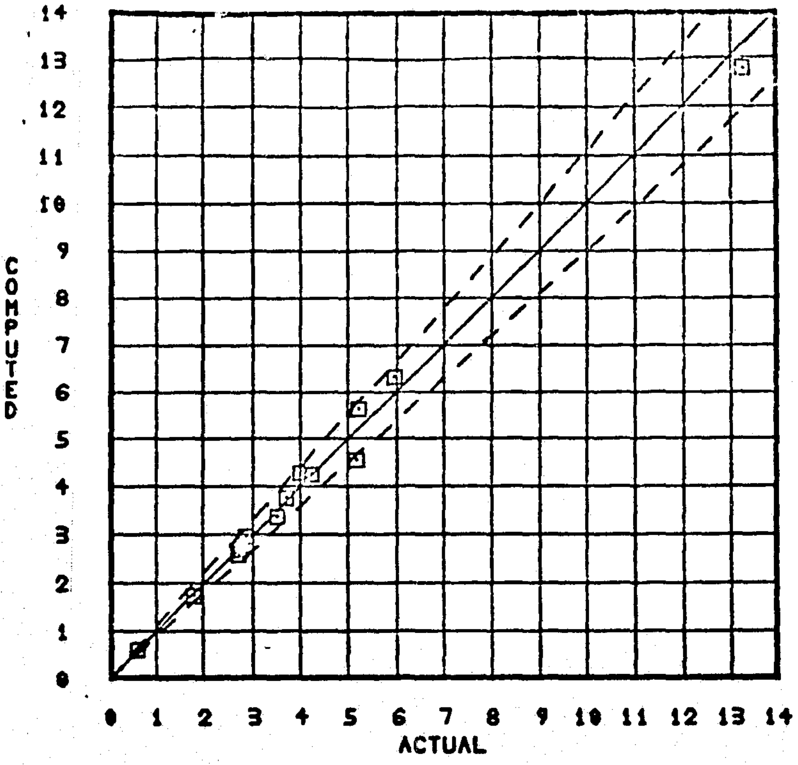
ENGINE LENGTH CALCULATED FROM INLET TEMPERATURE

FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION (cont'd)

13(a)

WEIGHT FOR AFTER BURNERS - 9 VARIBLES

SCALE FACTOR = 1000



PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
9	F100C

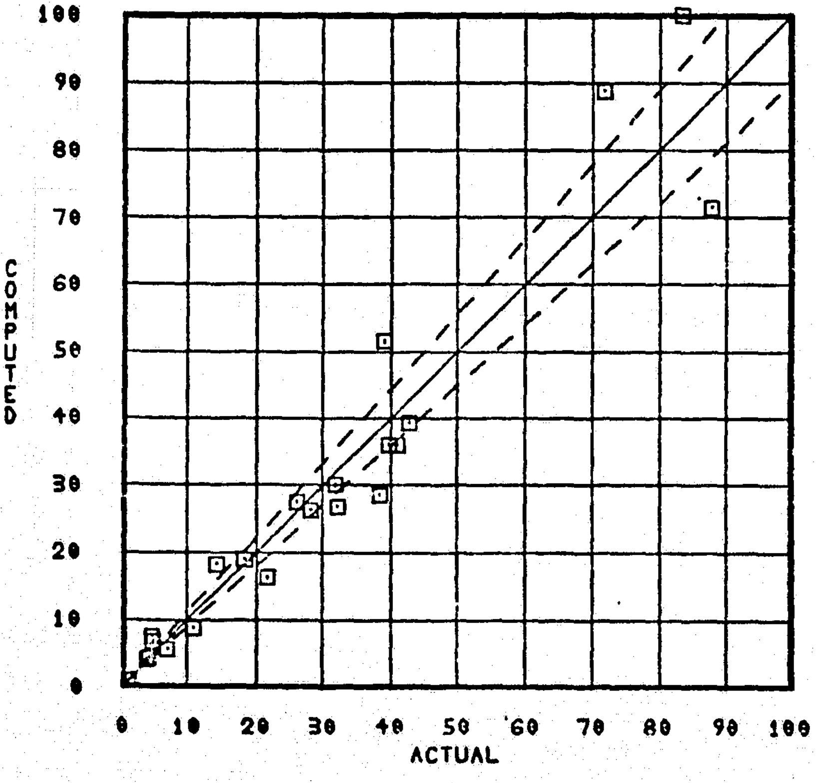
FIGURE 13

ENGINE CORRELATIONS BY ENGINE TYPES

13(b)

WEIGHT FOR NON-AFTER BURNERS - 9 VARIABLES

SCALE FACTOR = 100

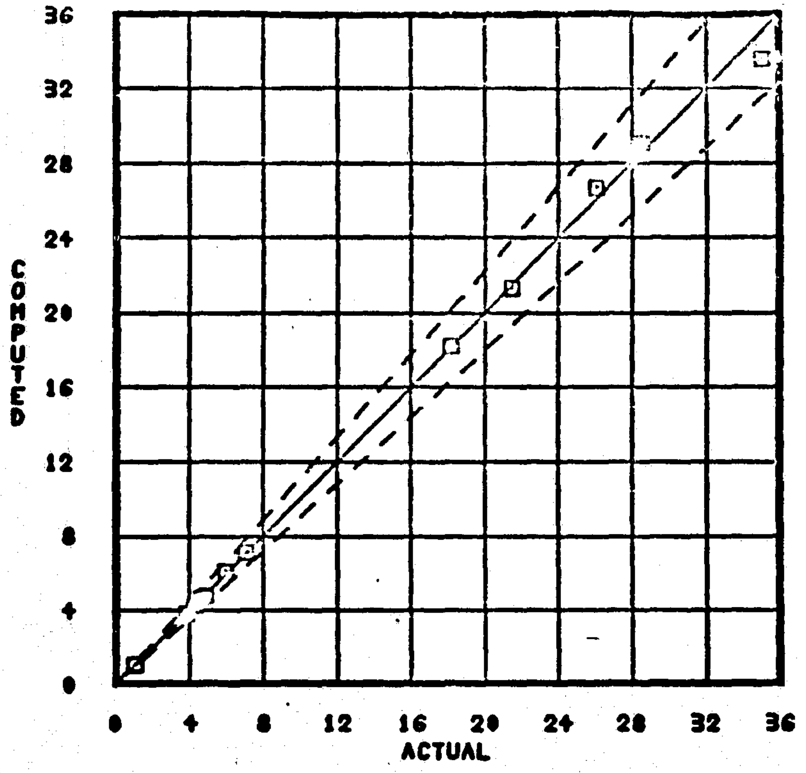


PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
2	B52H
5	A10A
6	DC10-30
7	747-200
8	727-200
16	C5A
18	YA9A
21	FLCM 10
27	HND DOG
28	T39A
30	B66A
31	F86H
33	-------

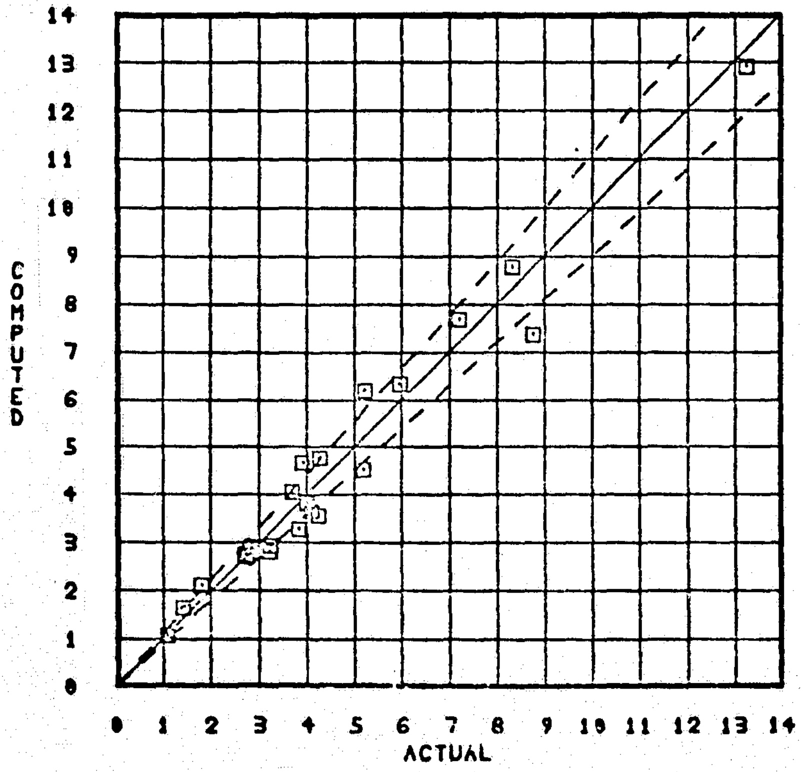
13(c)

WEIGHT FOR LIGHT ENGINES - 9 VARIBLES
SCALE FACTOR = 100



13(d)

WEIGHT FOR HEAVY ENGINES - 9 VARIBLES
SCALE FACTOR = 1000



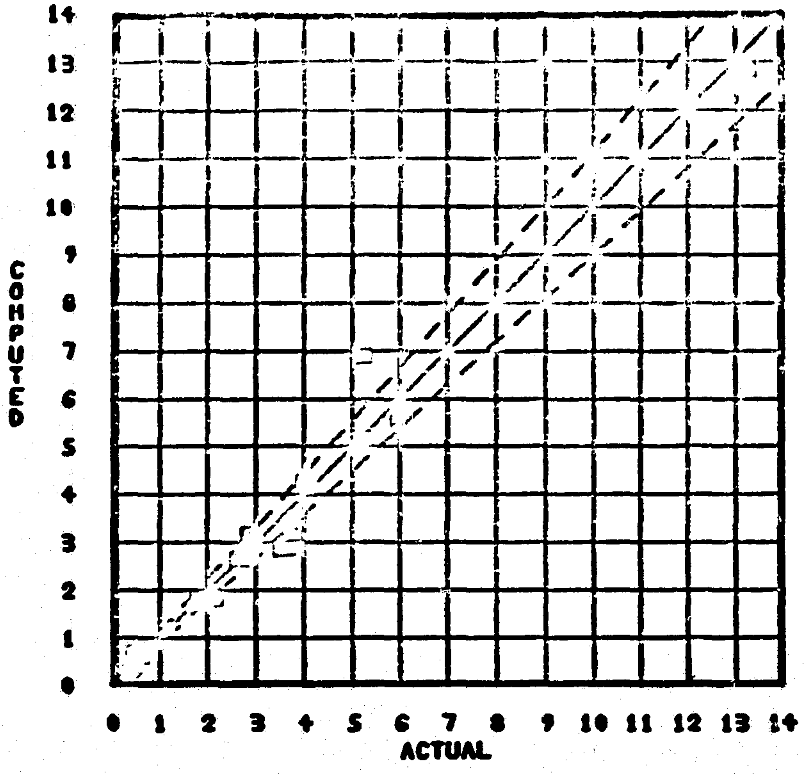
PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
2	B52H
4	B1A
5	A10A
7	747-200
9	F100C
13	B70
17	A7D
20	EC137D
30	B66A
31	F86H
32	-------

13(e)

WEIGHT FOR TURBOJETS - 9 VARIBLES

SCALE FACTOR = 1000



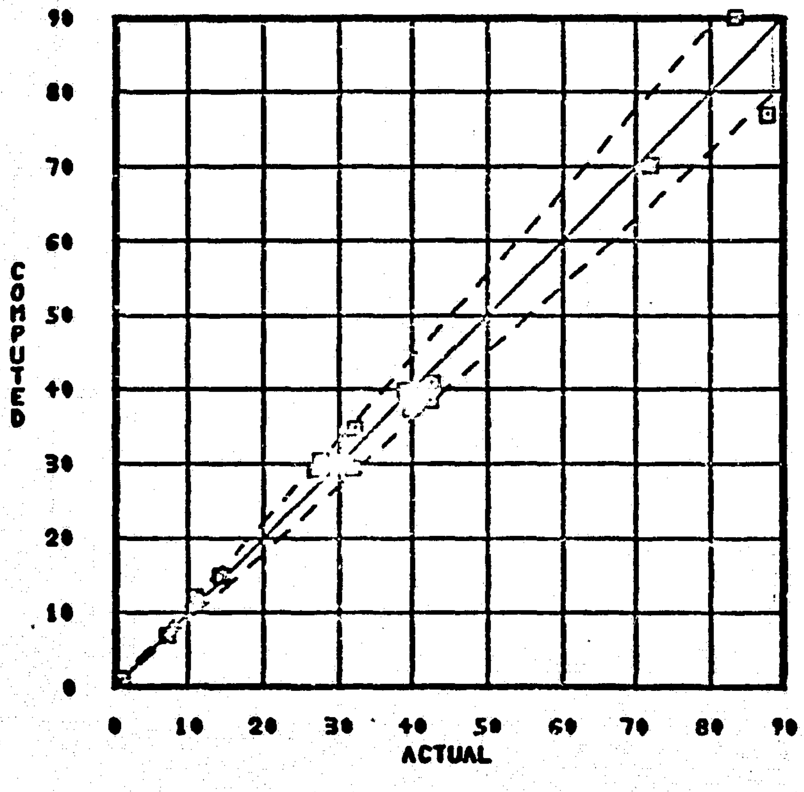
PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
13	B70
24	F89D
25	F86D
27	HMD D08
28	T39A
31	F86H
33	-------
34	-------
35	-------

13(f)

WEIGHT FOR TURBOFANS - 9 VARIBLES

SCALE FACTOR = 100



PLANES OUTSIDE 10%

NO.	AIRCRAFT ID
7	747-200

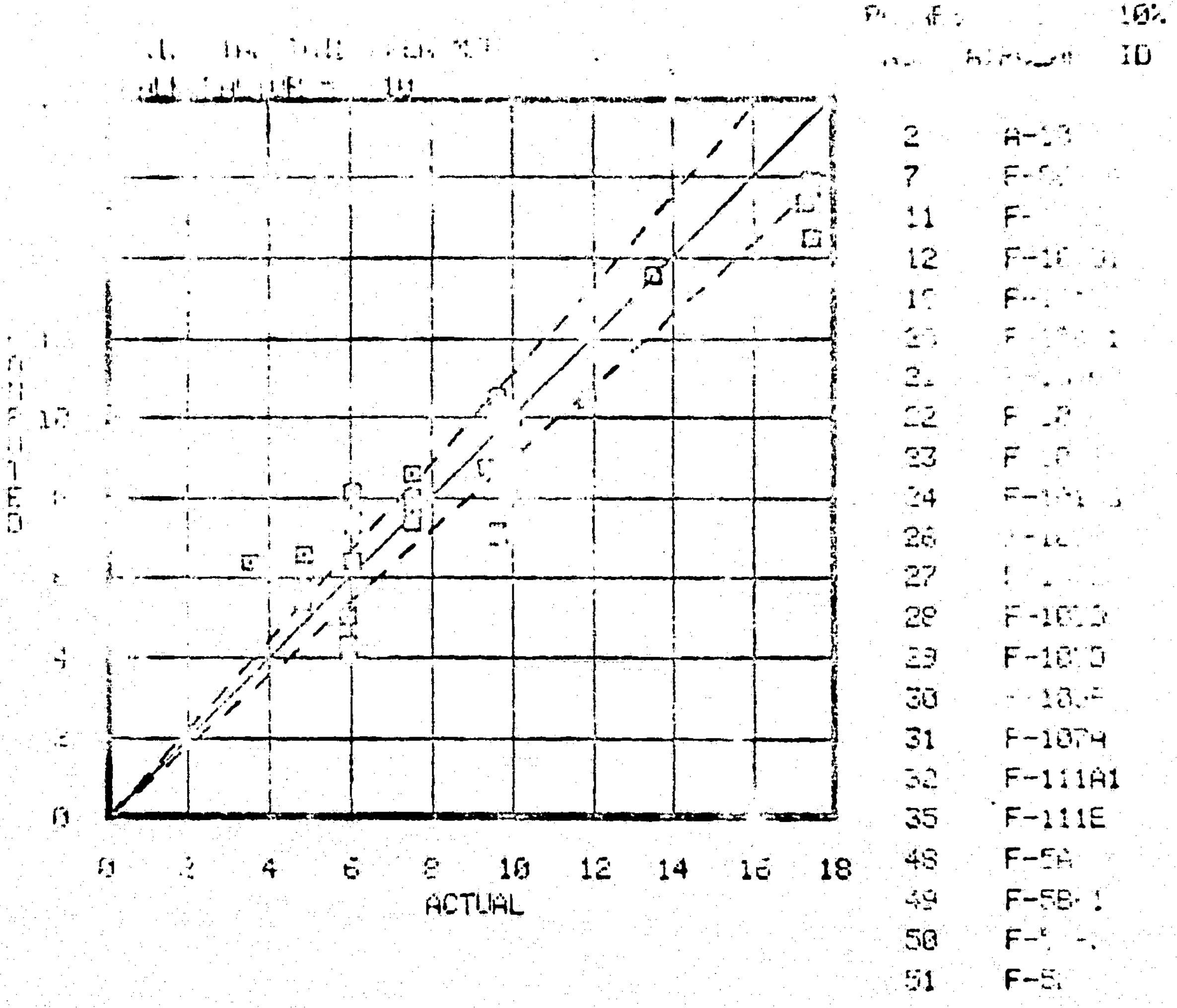


FIGURE 14. GEOMETRIC CORRELATION FOR MILITARY AIRCRAFT FROM TEKTONIX TERMINAL

TABLE I.

VEHICLES STORED IN MILITARY AIRCRAFT DATA BASE, M[1]

1. A-7D
2. A-10
3. A-37B-1
4. A-37B-2
5. F-86-D

6. F-86F-1
7. F-86F-40NA
8. XF-88A
9. F-89C
10. F-94C

11. F-100C
12. F-100D-1
13. F-100D-2
14. F-100F-1
15. F-100F-2

16. F-101A
17. RF-101A
18. F-101B
19. F-101C
20. F-104A-1

21. F-104A-2
22. F-104-C
23. F-104-F
24. F-104-G
25. F-105B-1

26. F-105B-10R
27. F-105D-1RE
28. F-105D-15R
29. F-105D-31R
30. F-105F-1RE

31. F-107A
32. F-111A-1
33. F-111A-2
34. F-111A-3
35. F-111E

36. F-4C-1
37. F-4C-2
38. F-4D
39. F-4E-1
40. F-4E-2

41. XF-92A
42. F-102A-1
43. F-102A-2
44. F-106A-1
45. F-106A-2

46. F-106B
47. F-108A
48. F-5A
49. F-5B-1
50. F-5B-2
51. F-5E

TABLE II.

VEHICLES CHARACTERISTICS STORED IN MILITARY AIRCRAFT DATA BASE, M[1]

1. Gross Weight
2. Design Load Factor
3. Wing Area
4. Aspect Ratio
5. Wing Span

6. t/c Root
7. t/c Tip
8. Taper Ratio C_T/C_R
9. Quarter Chord Sweep
10. Fuselage Length

11. Fuselage Depth
12. Fuselage Width
13. Tail Type (Conventional or TEE)
14. Horizontal Tail Area
15. Vertical Tail Area

16. Empty Weight
17. Sink Speed at Landing
18. Wing Weight Group
19. Wing Basic Structure Weight
20. Wing Secondary Structure Weight

21. Aileron Weight
22. Leading Edge Flap Weight
23. Trailing Edge Flap Weight
24. Slats Weight
25. Spoilers Weight

26. Total Tail Group Weight
27. Stabilizer Weight
28. Elevators Weight
29. Fin Weight
30. Rudder Weight

31. Body Group Weight
32. Fuselage Basic Structure Weight
33. Alighting Gear Group Weight
34. Main Landing Gear Weight
35. Nose Landing Gear Weight

36. Surface Control Group Weight
37. Cockpit Controls Weight
38. Autopilot Weight
39. System Controls Weight
40. A.P.U. Group Weight

41. Instrument & Navigation Group Weight
42. Hydraulic & Pneumatic Group Weight
43. Hydraulic System Weight
44. Pneumatic System Weight
45. Electrical Group Weight

46. Avionics Group Weight
47. Avionics Installation Weight
48. Furnishings Group Weight
49. Personnel Accomodations Weight
50. Furnishings Weight

51. Miscellaneous Equipment Weight
52. Emergency Equipment Weight
53. Air Conditioning & Anti-Icing Equipment Group Weight
54. Air Conditioning Weight
55. Anti-Icing Weight

TABLE III

VEHICLES IN THE TRANSPORT DATA BASE, M^2

1. F-27
2. L-188, Electra
3. C-130A
4. C-130A
5. C-130B

6. HC-130H
7. C-133A
8. C-133A
9. SE210-6N, Caravelle
10. 707-120

11. 707-020
12. 707-320
13. 707-320B
14. 720
15. C-135A

16. KC-135A
17. C-135B
18. DC-8-10
19. DC-8F-54
20. DC-8-62

21. 880
22. 990
23. F-2B
24. DC-9-10
25. DC-9-30

26. DC-9-30
27. 727-100
28. 727-200
29. 737-100
30. 737-200

31. 737-200
32. VC-10
33. VC-105
34. G141-2
35. C-5A

36. DC-10-10
37. 747-27
38. 747F
39. L1011
40. C-141-1

TABLE IV

VEHICLES CHARACTERISTICS IN THE TRANSPORT DATA BASE, M^2

1. Gross Weight
2. Design Load Factor
3. Wing Area
4. Aspect Ratio
5. Wing Span

6. t/c Root
7. t/c Tip
8. Taper Ratio C_t/C_R
9. Quarter Chord Sweep
10. Fuselage Length

11. Fuselage Maximum Depth
12. Fuselage Maximum Width
13. Tail Type
14. Horizontal Tail Area
15. Vertical Tail Area

16. Empty Weight
17. Sink Speed
18. Wing Group Weight
19. Wing Basic Structure Weight
20. Wing Secondary Structure Weight

21. Aileron Weight
22. Leading Edge Flap Weight
23. Trailing Edge Flap Weight
24. Slats Weight
25. Spoiler Weight

26. Total Tail Group Weight
27. Stabilizer Weight
28. Elevator Weight
29. Fin Weight
30. Rudder Weight

31. Body Group Weight
32. Fuselage Basic Structure Weight
33. Alighting Gear Group Weight
34. Main Landing Gear Weight
35. Nose Landing Gear Weight

36. Surface Control Group Weight
37. Cockpit Controls
38. Auto Pilot Weight
39. System Controls Weight
40. A.P.U. Group Weight

41. Instruments & Navigation Group Weight
42. Hydraulic Pneumatic Group Weight
43. Hydraulic System Weight
44. Pneumatic System Weight
45. Electrical Group Weight

46. Avionics Group Weight
47. Avionics Equipment Weight
48. Avionics Installation Weight

49. Furnishings Group Weight
50. Personnel Accommodations Weight

51. Personnel Furnishings Weight
52. Misc. Equipment Weight
53. Emergency Equipment Weight
54. Air Conditioning Group Weight
55. Air Conditioning System Weight

56. De-Ice System Weight
57. Number in Crew
58. Number of Stewardesses
59. Number of 1st Class Passengers
60. Number of Tourist Passengers

61. Aileron Area
62. Leading Edge Flap Area
63. Trailing Edge Flap Area
64. Slat Area
65. Spoiler Area

66. Stabilizer Area
67. Elevator Area
68. Fin Area
69. Rudder Area
70. Number of Engines

71. Engine Make
72. Engine Thrust
73. Nacelle Group Weight
74. Inboard Nacelle Weight
75. Outboard Nacelle Weight

76. Fuselage Wetted Area
77. Inboard Nacelle Length
78. Inboard Nacelle Depth
79. Inboard Nacelle Width
80. Outboard Nacelle Length

81. Outboard Nacelle Length
82. Outboard Nacelle Width
83. Total Aileron Area
84. Total Leading Edge Flap Area
85. Total Trailing Edge Flap Area

86. Total Slat Area
87. Total Spoiler Area
88. Maximum Dynamic Pressure
89. Altitude for Maximum g
90. Maximum Mach number

91. Cruise Speed Mach Number
92. Cruise Speed, Miles per Hour
93. Cruise Altitude

TABLE V.

TURBOJET AND TURBOFAN DATA BASE, M^3

No.	Engines	Aircraft	Manufacturer
1.	TF30-P100	F111F	Pratt and Whitney
2.	TF33P3	B52H	" " "
3.	XF100-PW100	F15A	" " "
4.	YF101-GE100	B1A	General Electric
5.	YTF34-GE-2	A10A	" "
6.	F103-GE-100 (CF6-500)	DC10-30	" "
7.	F105-PW-100 (JT9D-7)	747-200	Pratt and Whitney
8.	JT8D-9	727-200	" " "
9.	J57-F21A	F100C	" " "
10.	J75-P19W	F105D & F	" " "
11.	J79-GE- 15A	F4C & D	General Electric
12.	J85-GE-13A	F5A	" "
13.	YJ93-GE-3	B70	" "
14.	GE4/J5P	SST	" "
15.	J57-P19W	--	Pratt and Whitney
16.	TF39-GE-1	C5A	General Electric
17.	TF41-A-1	A7D	Allison
18.	YF102-LD-100	YA9A	Lycoming
19.	GE1/10F10C1	F15 Comp.	General Electric
20.	JT3D-3B	EC137D	Pratt and Whitney
21.	TFE-731-2	Dassault, Falcom 10, Learjet	Garrett
22.	WR19-A2	--	Williams
23.	J33-A-35	F80C	Allison
24.	J35-A-35	F89D	"
25.	J47-GE-27	F86D	General Electric
26.	J47-GE-27	F86F	" "
27.	J52-P-3	Hound Dog	Pratt and Whitney
28.	J60-P-3	T39A	" " "
29.	J65-W-5	B57A	Curtis Wright
30.	J71-A-13	B66A	Allison
31.	J73-GE-30	F86H	General Electric
32.	YJ101-GE-100	--	" "
33.	356-28	--	Continental
34.	J85-GE-5A	--	General Electric
35.	J-60	--	Pratt and Whitney

TABLE VI. ENGINE CHARACTERISTICS AVAILABLE IN ENGINE DATA BASE, M^3

1. Bypass Ratio
2. Overall Compressor Pressure Ratio
3. Outer Compressor Pressure Ratio
4. Number of Stages Low Pressure Compressor
5. Number of Stages High Pressure Compressor

6. Number of Stages Low Pressure Turbine
7. Number of Stages High Pressure Turbine
8. Fan Pressure Ratio
9. Turbine Maximum Inlet Temperature, °F
10. Nominal Engine Length, Inches

11. Weight, pounds
12. Sea Level Static Military Power Thrust
13. Sea Level Static Military Power Specific Fuel Consumption
14. Engine Mass Flow Sea Level Static Military Power, Pounds Per Second
15. Sea Level Static 5 Minute Maximum Power Thrust, Dry

16. Sea Level Static 5 Minute Maximum Power, Specific Fuel Consumption, Dry
17. Nominal Engine Diameter, Inches
18. ---
19. Month of Installation
20. Year of Installation

21. Total Number of Compressor Stages
22. Total Number of Turbine Stages
23. Wet/Dry Thrust Ratio (S.L.)
24. (1.0 + Bypass Ratio)
25. Thrust/Weight/S.L.
26. Thrust/Square Foot of Frontal Area (S.L.)

TABLE VII.

VEHICLES IN THE GENERAL AVIATION LIGHT AIRCRAFT DATA BASE, M^4

Manufacturer	Airplane
Aero Commander	Darter
	Lark
	Shrike
	Courser
American Aviation	Yankee
Beech	Musketeer Super
	Musketeer Sport
	Musketeer Custom
	Bonanza E33
	Bonanza E33A
	Bonanza E33B
	Bonanza E33C
	Bonanza V35A
	Bonanza TV35AA
	Bonanza 36
	Duke 60
	Baron B55
	Baron D55
	Turbobaron
	Queen Air A65
	Queen Air 70
	Queen Air B80
	Super H18
Cessna	150J-ST
	150J-CM
	172
	172 Skyhawk
	177A
	177CAR
	180H-SW
	182M
	182 Skylane
	185F-2
	U206D
	TP206D
	207 Skywagon
Cessna	210 JCEN
	210J-TC
	310P
	310P-TC
	337D
	337D-TC
	401A
	402A
	421A
Champion	7ECA
	7GCA-A
Moony	M10
	Ranger
	Chaparral
	Executive
	Statesman
	Mark 22
Piper	Super Cub
	140B-CH
	180CH.D
	235C-CH
	Arrow 180R
	Arrow 200R
	Cherokee 260.6B
	Cherokee 300C.6B
	Comanche 260
	Twin Comanche 160
	Twin Comanche 160-T
	Aztec 250D
	Aztec 250T
	Navajo 300
	Navajo-T
Bellanca	260C
Maule	M-4C
	M4-210C

TABLE VIII.

CHARACTERISTICS AVAILABLE IN THE GENERAL AVIATION LIGHT AIRCRAFT DATA BASE, M^4

1. Vehicle Gross Weight
2. Ultimate Load Factor at Design Weight
3. Wing Area
4. Geometric Span
5. Root Maximum Thickness
6. Body Length
7. Body Depth
8. Horizontal Tail Area
9. Vertical Tail Area
10. Payload Weight
11. Structural Span
12. Maximum Dynamic Pressure
13. Body Wetted Area (Approximate Value)
14. Thrust Per Engine
15. Number of Engines

```
M I S S I L E   I D E N T I F I C A T I O N          MISSILE NUMBER =   10
 MISSILF LAUNCH WEIGHT                        =   1000.0
 PAYLOAD WEIGHT, LBS.                         =   200.00
 PROPELLFNT WEIGHT, LBS.                      =   559.46
 MOTOR AND NOZZLE WEIGHT, LBS                 =   13.055
 POWER SYSTEM WEIGHT, LBS.                    =   19.623
 TAIL SURFACES WEIGHT, LBS.                   =   21.269
 AVIONICS SYSTEM WEIGHT, LBS.                 =   104.45
 BODY STRUCTURAL WEIGHT, LBS.                 =   44.056
 ORIENTATION CONTROL SYSTEM WEIGHT, LBS=          38.081
 LAUNCH VELOCITY, F.P.S.                      =   1000.0
 LAUNCH ALTITUDE, FEET                        =   30000.
 FUEL UTILIZATION FACTOR                      =   1.0000
 FUEL FLOW, LBS/SEC.                          =   5.6604
 CONFIGURATION SPAN, FEET                     =   2.3119
 PITCH INERTIA ABOUT C.G., LBS-FEET**2        =   16131.
 LAUNCH/MAX. DYNAMIC PRESSURE, LB/FT**2=          2000.0
 AVERAGE MISSILE DENSITY, LB/FT**2            =   80.000
 S. F. C., LBS THRUST/( LBS /SEC)             =   265.00
 WETTED ARFA, FT**2                           =   46.483
 EXPOSED TAIL AREA  , FT**2                   =   2.0389
 THRUST, LBS.                                 =   1500.0
 THRUST/WEIGHT                                =   1.5000
 BODY PACKAGING VOLUME, FT**3                 =   11.639
 TAIL L. E. SWEEP, DEGREES                    =   61.339
 TAIL EXPOSED SPAN, FT.                       =   1.2844
```

TABLE IX. TYPICAL ASM DATA BASE OUTPUT

```
M I S S I L E   I D E N T I F I C A T I O N          MISSILE NUMBER =   10

TAIL ROOT CHORD, FT.                           =   2.1750

TAIL TIP CHORD, FEET                           =   1.0000

CONFIGURATION PLANFORM AREA,                   =   16.792

CONFIGURATION REF. AREA,FT.                    =   .82919

BODY WEIGHT MULTIPLER                          =   .33300

BODY DEPTH, FEET                               =   1.0275

BODY LENGTH, FEET                              =   15.000

FIRST STAGE BURN TIME,SECS                     =   98.839

BODY STATION NUMBER 1                          =  0.

BODY STATION NUMBER 2                          =   .37500

BODY STATION NUMBER 3                          =   .75000

BODY STATION NUMBER 4                          =   1.1250

BODY STATION NUMBER 5                          =   1.5000

BODY STATION NUMBER 6                          =   3.0000

BODY STATION NUMBER 7                          =   4.5000

BODY STATION NUMBER 8                          =   6.0000

BODY STATION NUMBER 9                          =   7.5000

BODY STATION NUMBER 10                         =   9.0000

BODY STATION NUMBER 11                         =   10.500

BODY STATION NUMBER 12                         =   12.000

BODY STATION NUMBER 13                         =   13.500

BODY STATION NUMBER 14                         =   15.000

BODY AREA NUMBER 1                             =  0.

BODY AREA NUMBER 2                             =   .13256

BODY AREA NUMBER 3                             =   .36676
```

TABLE IX. TYPICAL ASM DATA BASE OUTPUT (cont'd)

```
M I S S I L E   I D E N T I F I C A T I O N          MISSILE NUMBER =   10
 BODY AREA NUMBER 4                          =   .58769
 BODY AREA NUMBER 5                          =   .74754
 BODY AREA NUMBER 6                          =   .82919
 BODY AREA NUMBER 7                          =   .82919
 BODY AREA NUMBER 8                          =   .82919
 BODY AREA NUMBER 9                          =   .82919
 BODY AREA NUMBER 10                         =   212.19
 BODY AREA NUMBER 11                         =   .82919
 BODY AREA NUMBER 12                         =   .82919
 BODY AREA NUMBER 13                         =   .82919
 BODY AREA NUMBER 14                         =   .82919
 BEGIN AVIONICS AT STATION                   =   .75000
 BEGIN PAYLOAD  AT STATION                   =   2.5382
 BEGIN POWER SYSTEM AT STATION               =   5.5532
 BEGIN ORIENTATION CONTOL SYSTEM AT X        =   5.8490
 BEGIN PROPELLENT SECTION AT STATION         =   6.4231
 BEGIN MOTOR SECTION AT STATION              =   14.803
 DOWN RANGE, N.M.                            =   212.19
 CROSS RANGE,N.M.                            =   5.5800
 FIRST CONTROL PARAMETER                     =   33.800
 SECOND CONTROL PARAMETER                    =   42.400
```

TABLE IX. TYPICAL ASM DATA BASE OUTPUT (CONCLUDED)

	NUMBER	TYPE	a	V1	V2	V3	V4	V5	V6	V7	V8	V9
All engines	1.	I	14.4552	$T^{.456945}$	$Y^{-.101502}$	$L^{.646774}$	$ABR^{-.21799}$	$NC^{.172602}$	$D^{.653298}$	$B^{-.069142}$	$TIT^{-.307745}$	$NT^{-.096741}$
	2.	I'	1754.20	$T^{.549993}$	$Y^{-1.692094}$	$ABR^{.477372}$	$NC^{.280225}$	$D^{.993875}$	$B^{-.160962}$	$NT^{-.109324}$	$TIT^{-.256799}$	
	3.	I'_{35}	3098.76	$T^{.462441}$	$Y^{-2.16958}$	$ABR^{.625720}$	$D^{1.193809}$	$NC^{.288089}$	$B^{-.190094}$	$TIT^{-.013804}$	$NT^{-.014360}$	
No afterburner	4.	III'	5.144×10^{6}	$T^{.620898}$	$Y^{-3.79743}$	$OCR^{.777523}$	$NT^{-.301296}$	$NC^{.177550}$	$D^{.400351}$	$TIT^{-.153951}$	$B^{.009151}$	
	5.	III'	24.4635	$T^{.500372}$	$Y^{-2.26234}$	$NC^{.260217}$	$TIT^{.706416}$	$B^{-.263909}$	$D^{.958186}$	$NT^{-.044924}$	(Too small a sample)	
Afterburners	6.	II'	1167.66	$D^{.543631}$	$NC^{.612455}$	$TIT^{-1.76318}$	$T^{1.00435}$	$NT^{-.001159}$	$ABR^{2.35517}$	$B^{-.114642}$	$Y^{.271035}$	
Fan engines	7.	IV'	.028897	$T^{.732583}$	$B^{-.135132}$	$D^{.692224}$	$NT^{-.336031}$	$TIT^{-.932994}$	$Y^{2.03140}$	$NC^{.362712}$	$ABR^{.129214}$	
No fan engines	8.	V'	8.87673	$T^{.233221}$	$Y^{-2.32122}$	$NC^{.376819}$	$D^{1.09927}$	$NT^{.224777}$	$TIT^{.724221}$	(limit of significance)		
Small engines *	9.	VI'_{35}	4.6693×10^{-11}	$D^{1.82327}$	$NC^{.317237}$	$B^{-.148675}$	$TIT^{4.51954}$	$ABR^{.812184}$	$Y^{-2.36457}$	$NT^{-.333467}$	$T^{.013454}$	
Large engines *	10.	VII'	1357.66	$T^{1.07330}$	$Y^{-1.10784}$	$ABR^{.399984}$	$TIT^{-.667357}$	$NT^{-.207024}$	$NC^{.400361}$	(End of Calculation)		

NOTE: Prime indicates length not used in weight estimating relationship.
Subscript 35 indicates 35 engine data base used.
* Indicates 6000 pounds of thrust

TABLE X. ENGINE WEIGHT ESTIMATING RELATIONSHIPS

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