Multivariate Analysis, Retrieval, and Storage System (MARS)

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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

\[ \Delta W = aX_1 + b_2X_2 + \cdots + b_nX_n \]

Where \( \Delta W \) 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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AEROPHYSICS RESEARCH CORPORATION

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:

\[ W_i = a_i x_{i1}^{b_{1i}} x_{i2}^{b_{2i}} \cdots x_{in}^{b_{ni}} \]

where

- \( W_i \) is the weight estimate for component \( i \).
- \( a_i \) is the multiplicative constant for component \( i \) weight estimation.
- \( b_{ri} \) is the \( r \)th exponential constant for estimating the weight of component \( i \).
- \( x_{ri} \) is the \( r \)th 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.
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.

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

\[ W_i = a_1 + b_1 x_1 + b_2 x_2 + \cdots + b_N x_N \]

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 \( [M_{ij}] \) where the row index \( i \) designates vehicle or engine type and the column index \( j \) designates a particular characteristic. Thus the \( i^{th} \) row \( [M_{i}] \) contains all known information about the \( i^{th} \) vehicle or engine. The \( j^{th} \) column \( \{M_j\} \) 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 \( [m_{r,s}] \). Therefore

\[
[m_{r,s}] = \{M_{s_1}, M_{s_2}, \ldots, M_{s_{10}}\}
\]

The reduced size dynamic data base, \( [m_{r,s}] \) thus contains up to ten characteristics for all vehicles or engines in a selected permanent data base. The selected columns

\( j = s_1, s_2, \ldots, s_{10} \)

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

\[
W_i = a_1 X_1 + a_2 X_2 + \ldots + a_n X_n
\]

where \( W_i \) is a characteristic variable whose sample values are contained in any one of the columns \( \{m_s\} \) 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 \( M^1 \) database. 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, M⁴**

Characteristic data for 71 general aviation light aircraft are stored in the data base, M⁴. 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, M⁴. 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, M⁵ and M⁶**

Characteristic data for more than 100 Air-to-Surface Missiles (ASM) are stored in the ASM data bases, M⁵ and M⁶. Characteristics are theoretical and were computed by the vehicle design synthesis and trajectory optimization studies of Reference 7. Characteristics contained in the M⁵ and M⁶ 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

\[ Q_{ij} = \sum_{i=1}^{M} \sum_{j=1}^{N} W_i W_j X_i X_j \]

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

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

\[ (\text{Cov})_{ij} = \sum_{i=1}^{M} \sum_{j=1}^{N} W_i W_j (X_i - \bar{X}_i) (X_j - \bar{X}_j) \]

From this the program computes the vector characteristic variable standard deviations

\[ \sigma_i = \sqrt{(\text{Var})_i} \]

and the matrix of characteristic variable linear correlation coefficients

\[ p_{ij} = \frac{(\text{Cov})_{ij}}{\sigma_i \sigma_j} \]

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

\[ Y_r = a_r X_1 + b_2 X_2 + \ldots + b_R X_R \]
Thus, the first equation is of the form

\[ Y_1 = a_1 x_1 \]

the next is

\[ Y_2 = a_2 x_1 x_2 \]

This process continues until the \( r \)th expression is generated

\[ Y_R = a_R x_1 x_2 \cdots x_R \]

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 $X_i$, not 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 in 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.
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

\[ Y = a x_1^{b_1} x_2^{b_2} \ldots \ldots \ldots x_9^{b_9} \]

Using the MARS system the following equation is obtained:

\[ Y = 0.16384 \times (\text{Ultimate Load Factor})^{-0.01233} \]

\[ X (\text{Wing Area})^{1.2226} \]

\[ X (\text{Wing Aspect Ratio})^{2.200} \]

\[ X (\text{Wing Root Thickness})^{0.3305} \]

\[ X (\text{Wing Quarter Chord Sweep})^{0.06188} \]

\[ X (\text{Fuselage Maximum Depth})^{0.5819} \]

\[ X (\text{Fuselage Length})^{1.0399} \]

\[ X (\text{Horizontal Tail Area})^{-0.05446} \]

\[ X (\text{Vertical Tail Area})^{0.07659} \]

Further the relative statistical significance of the variables \( X_1 \) to \( X_9 \) is found to be:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Load Factor</td>
<td>9th</td>
</tr>
<tr>
<td>Wing Area</td>
<td>1st</td>
</tr>
<tr>
<td>Wing Aspect Ratio</td>
<td>7th</td>
</tr>
<tr>
<td>Wing Root Thickness</td>
<td>6th</td>
</tr>
<tr>
<td>Wing Quarter Chord Sweep</td>
<td>3rd</td>
</tr>
<tr>
<td>Fuselage Maximum Depth</td>
<td>4th</td>
</tr>
<tr>
<td>Fuselage Length</td>
<td>2nd</td>
</tr>
<tr>
<td>Horizontal Tail Area</td>
<td>8th</td>
</tr>
<tr>
<td>Vertical Tail Area</td>
<td>5th</td>
</tr>
</tbody>
</table>
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 \( \pm 10\% \) 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 than the computed weight. Therefore, vehicle predicted empty weights in the lower triangular region indicate a heavier than average aircraft. Similarly, when the predicted empty weight is in the upper triangular region an aircraft is lighter than average.

In the example of Figure 9 (a) only two vehicle empty weight predictions are in error by more than 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 than 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

\[ W = 9.46 L^{.587} S^{.308} D^{.264} A^{.037} S^{.287} T^{-.335} S^{.143} N^{1.155} A R^{-.111} \]

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 vehicle 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

CENTRAL COMPUTER FACILITY
IBM 360 COMPUTER
TSS
HIGH SPEED GRAPHICS LINE
TIME-SHARE SYSTEM

IBM 1570

IMLAC COMPUTER
8K, 16 bit

DISC DRIVE
2.5 Million Words Storage

DISC DRIVE
REMOVABLE DISC CARTRIDGE
FIXED DISC

MODEL 33 TELETYPewriter

TELETYPE HILAC DISPLAY

INCREMENTAL PLOTTER

GRAPHICAL INPUT TABLET
FIGURE 3. SCHEMATIC OF MARS PROGRAM OPERATIONS
**Vehicle Identification**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Gross Weight, Pounds</td>
<td>37500</td>
</tr>
<tr>
<td>Ultimate Load Factor, G.</td>
<td>12.750</td>
</tr>
<tr>
<td>Wing Area, ft**2</td>
<td>538.30</td>
</tr>
<tr>
<td>Wing Aspect Ratio</td>
<td>2.7390</td>
</tr>
<tr>
<td>Wing Span, Feet</td>
<td>38.400</td>
</tr>
<tr>
<td>T/C at Root</td>
<td>0.63830E-01</td>
</tr>
<tr>
<td>T/C at Tip</td>
<td>0.27100E-01</td>
</tr>
<tr>
<td>Tip Chord/Root Chord</td>
<td>1.3666</td>
</tr>
<tr>
<td>Cosine (Wing .25 Chord Line)</td>
<td>45.000</td>
</tr>
<tr>
<td>Fuselage Length, Feet</td>
<td>51.800</td>
</tr>
<tr>
<td>Fuselage Max. Depth, ft</td>
<td>6.3000</td>
</tr>
<tr>
<td>Fuselage Max. Width, ft</td>
<td>7.8000</td>
</tr>
<tr>
<td>Tail Type Case</td>
<td>1.0000</td>
</tr>
<tr>
<td>Horizontal Tail Area, ft**2</td>
<td>96.200</td>
</tr>
<tr>
<td>Vertical Tail Area, ft**2</td>
<td>67.500</td>
</tr>
<tr>
<td>Empty Weight, Pounds</td>
<td>28541.0</td>
</tr>
<tr>
<td>Sink Speed, ft/second</td>
<td>10.030</td>
</tr>
<tr>
<td>Wing Group Weight</td>
<td>4670.0</td>
</tr>
<tr>
<td>Wing Basic Structure WT.</td>
<td>3331.0</td>
</tr>
<tr>
<td>Wing Secondary Structure WT.</td>
<td>465.00</td>
</tr>
<tr>
<td>Aileron Weight</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>L.E. Flap Weight</td>
<td>494.00</td>
</tr>
<tr>
<td>T.E. Flap Weight</td>
<td>180.00</td>
</tr>
<tr>
<td>Slats Weight</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Spoilers Weight</td>
<td>154.00</td>
</tr>
<tr>
<td>Tail Group Weight</td>
<td>953.00</td>
</tr>
<tr>
<td>Stabilizer Weight</td>
<td>667.00</td>
</tr>
<tr>
<td>Elevator Weight</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Fin Weight</td>
<td>222.00</td>
</tr>
<tr>
<td>Rudder Weight</td>
<td>64.000</td>
</tr>
<tr>
<td>Body Group Weight</td>
<td>4919.0</td>
</tr>
<tr>
<td>Fuselage Basic Structure</td>
<td>3044.0</td>
</tr>
<tr>
<td>Landing Gear Weight</td>
<td>1968.0</td>
</tr>
<tr>
<td>Main Landing Gear Weight</td>
<td>1592.0</td>
</tr>
<tr>
<td>Nose Landing Gear Weight</td>
<td>376.00</td>
</tr>
<tr>
<td>Surface Control Group WT.</td>
<td>975.00</td>
</tr>
</tbody>
</table>

**Figure 4. F4E Weight Summary from Data Base**
<table>
<thead>
<tr>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>COCKPIT CONTROL WEIGHT</td>
<td>73.00</td>
</tr>
<tr>
<td>AUTOPILOT WEIGHT</td>
<td>63.00</td>
</tr>
<tr>
<td>SYSTEM CONTROLS WEIGHT</td>
<td>840.00</td>
</tr>
<tr>
<td>A.P.U. GROUP WEIGHT</td>
<td>0.1111E-09</td>
</tr>
<tr>
<td>INSTR. + NAVIGATION GROUP WT.</td>
<td>256.00</td>
</tr>
<tr>
<td>HYD. + PNEUMATIC GROUP WT.</td>
<td>523.00</td>
</tr>
<tr>
<td>HYDRAULIC SYSTEM WEIGHT</td>
<td>0.1111E-08</td>
</tr>
<tr>
<td>PNEUMATIC SYSTEM WEIGHT</td>
<td>0.1111E-08</td>
</tr>
<tr>
<td>ELECTRICAL SYSTEM WEIGHT</td>
<td>527.00</td>
</tr>
<tr>
<td>AVIONICS GROUP WEIGHT</td>
<td>1399.0</td>
</tr>
<tr>
<td>AVIONICS EQUIPMENT WEIGHT</td>
<td>1414.0</td>
</tr>
<tr>
<td>AVIONICS INSTALLATION WEIGHT</td>
<td>485.00</td>
</tr>
<tr>
<td>FURNITURE GROUP WT.</td>
<td>521.00</td>
</tr>
<tr>
<td>PERSONNEL ACCOMMODATIONS WT.</td>
<td>391.00</td>
</tr>
<tr>
<td>PERSONNEL FURNISHING WEIGHT</td>
<td>20.00</td>
</tr>
<tr>
<td>MISCELLANEOUS WEIGHT</td>
<td>38.00</td>
</tr>
<tr>
<td>EMERGENCY EQUIPMENT WEIGHT</td>
<td>22.00</td>
</tr>
<tr>
<td>AIR CONDITIONING GROUP WT.</td>
<td>399.00</td>
</tr>
<tr>
<td>AIR CONDITIONING SYSTEM WT.</td>
<td>0.1111E-08</td>
</tr>
<tr>
<td>DE ICER SYSTEM WT.</td>
<td>399.00</td>
</tr>
<tr>
<td>COMPUTED QUARTER CHORD SPAN</td>
<td>0.35373</td>
</tr>
<tr>
<td>COMPUTED ROOT CHORD</td>
<td>11.847</td>
</tr>
<tr>
<td>COMPUTED ROOT THICKNESS</td>
<td>0.75582</td>
</tr>
<tr>
<td>VERTICAL TAIL WT.</td>
<td>286.00</td>
</tr>
<tr>
<td>HORIZONTAL TAIL WT.</td>
<td>667.00</td>
</tr>
<tr>
<td>COMPUTED BODY AREA</td>
<td>1241.6</td>
</tr>
<tr>
<td>COMPUTED NON-BASIC BODY WT.</td>
<td>1875.0</td>
</tr>
<tr>
<td>APPROX. MAXIMUM PRESSURE</td>
<td>999.00</td>
</tr>
</tbody>
</table>

**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 = 137.60
T/C AT ROOT = 0.17940
T/C AT TIP = 0.12000
TIP CHORD/ROOT CHORD = 0.52130
COSINE (WING .25 CHORD LINE) = 0.03000
FUSELAGE LENGTH, FEET = 95.750
FUSELAGE MAX. DEPTH, FT = 13.250
FUSELAGE MAX. WIDTH, FT = 14.160
TAIL TYPE CASE = 0.11111E-08
HORIZONTAL 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
AILEPCN WEIGHT = 412.00
L.E. FLAP WEIGHT = 0.11111E-08
T.F. FLAP WEIGHT = 1056.0
SLATS WEIGHT = 0.11111E-08
SPOILERS WEIGHT = 0.11111E-08
TAIL GROUP WEIGHT = 3192.0
STABILIZER WEIGHT = 1266.0

FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE
<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevator Weight</td>
<td>967.00</td>
</tr>
<tr>
<td>Fin Weight</td>
<td>845.00</td>
</tr>
<tr>
<td>Rudder Weight</td>
<td>274.00</td>
</tr>
<tr>
<td>Body Group Weight</td>
<td>13356.00</td>
</tr>
<tr>
<td>Fuselage Basic Structure</td>
<td>9701.0</td>
</tr>
<tr>
<td>Landing Gear Weight</td>
<td>4321.0</td>
</tr>
<tr>
<td>Main Landing Gear Weight</td>
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</tr>
<tr>
<td>Nose Landing Gear Weight</td>
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</tr>
<tr>
<td>Surface Control Group Weight</td>
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</tr>
<tr>
<td>Cockpit Control Weight</td>
<td>106.00</td>
</tr>
<tr>
<td>Autopilot Weight</td>
<td>204.00</td>
</tr>
<tr>
<td>System Controls Weight</td>
<td>1170.0</td>
</tr>
<tr>
<td>A.P.G. Group Weight</td>
<td>411.00</td>
</tr>
<tr>
<td>Inst. + Navigation Group Weight</td>
<td>613.00</td>
</tr>
<tr>
<td>Hyd. + Pneumatic Group Weight</td>
<td>1667.00</td>
</tr>
<tr>
<td>Hydraulic System Weight</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Pneumatic System Weight</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Electrical System Weight</td>
<td>1865.0</td>
</tr>
<tr>
<td>Avionics Group Weight</td>
<td>1850.0</td>
</tr>
<tr>
<td>Avionics Equipment Weight</td>
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</tr>
<tr>
<td>Avionics Installation Weight</td>
<td>584.00</td>
</tr>
<tr>
<td>Furniture Group Weight</td>
<td>3259.0</td>
</tr>
<tr>
<td>Personnel Accommodations Weight</td>
<td>1680.0</td>
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<tr>
<td>Personnel Furnishing Weight</td>
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</tr>
<tr>
<td>Miscellaneous Weight</td>
<td>669.00</td>
</tr>
<tr>
<td>Emergency Equipment Weight</td>
<td>426.00</td>
</tr>
<tr>
<td>Air Conditioning Group Weight</td>
<td>7757.0</td>
</tr>
</tbody>
</table>

**Figure 5.** Characteristics of C130A from Transport Data Base (cont'd)
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Conditioning System Weight</td>
<td>1316.0</td>
</tr>
<tr>
<td>DE ICFR System Weight</td>
<td>941.00</td>
</tr>
<tr>
<td>Number in Crew</td>
<td>4.0000</td>
</tr>
<tr>
<td>Number of Stewardesses</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>No. of 1st Class Passengers</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>No. of Tourist Passengers</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Aileron Area</td>
<td>110.00</td>
</tr>
<tr>
<td>Leading Edge Flap Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Trailing Edge Flap Area</td>
<td>342.00</td>
</tr>
<tr>
<td>Slat Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Spoiler Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Stabilizer Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Elevator Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Fin Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Rudder Area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Number of Engines</td>
<td>4.0000</td>
</tr>
<tr>
<td>Engine Make</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Engine Thrust</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Nacelle Group Weight</td>
<td>2720.0</td>
</tr>
<tr>
<td>Inboard Nacelle Weight</td>
<td>1274.0</td>
</tr>
<tr>
<td>Outboard Nacelle Weight</td>
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</tr>
<tr>
<td>Fuselage Wetted Area</td>
<td>3460.0</td>
</tr>
<tr>
<td>Inboard Nacelle Length</td>
<td>19.500</td>
</tr>
<tr>
<td>Inboard Nacelle Depth</td>
<td>5.0000</td>
</tr>
<tr>
<td>Inboard Nacelle Width</td>
<td>3.1700</td>
</tr>
<tr>
<td>Outboard Nacelle Length</td>
<td>20.400</td>
</tr>
<tr>
<td>Outboard Nacelle Depth</td>
<td>5.0000</td>
</tr>
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</table>

**FIGURE 5.** CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE (cont'd)
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outboard nacelle width</td>
<td>3.1700</td>
</tr>
<tr>
<td>Total aileron area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Total L.E. flap area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Total T.E. flap area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Total slat area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Total spoiler area</td>
<td>0.11111E-08</td>
</tr>
<tr>
<td>Maximum dynamic pressure</td>
<td>300.00</td>
</tr>
<tr>
<td>Altitude for maximum g</td>
<td>10000.00</td>
</tr>
<tr>
<td>Maximum Mach number</td>
<td>0.54000</td>
</tr>
<tr>
<td>Cruise speed in Mach number</td>
<td>0.50000</td>
</tr>
<tr>
<td>Cruise speed in MPH</td>
<td>360.00</td>
</tr>
<tr>
<td>Cruise altitude</td>
<td>10000.00</td>
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</tbody>
</table>

**FIGURE 5. CHARACTERISTICS OF C130A FROM TRANSPORT DATA BASE (cont'd)**
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass Ratio</td>
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</tr>
<tr>
<td>Overall Compressor Pressure Ratio</td>
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</tr>
<tr>
<td>Cutep Compressor Pressure Ratio</td>
<td>1.0000</td>
</tr>
<tr>
<td>No. of Stages, Low Pressure Compressor</td>
<td>0.00000</td>
</tr>
<tr>
<td>No. of Stages, High Pressure Compressor</td>
<td>9.0000</td>
</tr>
<tr>
<td>No. of Stages, Low Pressure Turbine</td>
<td>0.00000</td>
</tr>
<tr>
<td>No. of Stages, High Pressure Turbine</td>
<td>2.0000</td>
</tr>
<tr>
<td>Fan Pressure Ratio</td>
<td>1.0000</td>
</tr>
<tr>
<td>Turbine Max. Inlet Temp. Degrees F</td>
<td>1600.0</td>
</tr>
<tr>
<td>Nominal Engine Length, Inches</td>
<td>79.500</td>
</tr>
<tr>
<td>Weight in Pounds</td>
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</tr>
<tr>
<td>S.L. Static MIL. Power (30 Min. Max.)</td>
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</tr>
<tr>
<td>S.L. S.F.C. MIL. Power (30 Min. Max.)</td>
<td>0.96000</td>
</tr>
<tr>
<td>Engine Mass Flow S.L. Static, LBS/SEC</td>
<td>50.000</td>
</tr>
<tr>
<td>S.L. Static Max. A/B Thrust</td>
<td>-1.0000</td>
</tr>
<tr>
<td>S.L. Static Max. A/B S.F.C.</td>
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</tr>
<tr>
<td>Nominal Engine Diameter, Inches</td>
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<tr>
<td>Installation Month</td>
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<tr>
<td>Installation Year</td>
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<tr>
<td>Total Number of Comp. Stages</td>
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<td>Total Number of Turbine Stages</td>
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<tr>
<td>A/B Thrust to Non A/B Thrust Ratio</td>
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</tr>
<tr>
<td>Bypass Ratio + 1</td>
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<tr>
<td>Thrust/Weight</td>
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<tr>
<td>Thrust per Square Inch</td>
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**Figure 6. Characteristics of J60-P-3 Engine from Engine Data Base**
EMPTY WEIGHT FROM 9 VARIABLES (TRANSPORTS)
SCALE FACTOR = 1000

PLANES OUTSIDE 10%

<table>
<thead>
<tr>
<th>NO.</th>
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<tbody>
<tr>
<td>2</td>
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<tr>
<td>6</td>
<td>HC-130H</td>
</tr>
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<td>18</td>
<td>DC-8-10</td>
</tr>
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<td>23</td>
<td>F-2B</td>
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<td>32</td>
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FIGURE 7. TYPICAL GRAPHICAL OUTPUT
### Table 1: Typical Regression Analysis Final Output

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<th>Calculated Value</th>
<th>Difference</th>
<th>Ratio</th>
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<td>V-77</td>
<td>7684.2, 524</td>
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<td>-0.135E-03</td>
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<tr>
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<td>-0.155E-03</td>
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<td>-0.083E-03</td>
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<td>-0.083E-03</td>
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**Figure 8. Typical Regression Analysis Final Output**
FIGURE 9. MILITARY AIRCRAFT
FIGURE 9. MILITARY AIRCRAFT (cont'd)
FIGURE 9. MILITARY AIRCRAFT (cont'd)
FIGURE 10. TRANSPORT AIRCRAFT
FIGURE 10. TRANSPORT AIRCRAFT (cont'd)
FIGURE 10. TRANSPORT AIRCRAFT (cont'd)
FIGURE 11. TURBOJET & TURBOFAN ENGINES
FIGURE 11. TURBOJET & TURBOFAN ENGINES (cont'd)
FIGURE 11. TURBOJET & TURBOFAN ENGINES (cont'd)
FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION

12(a) ENGINE LENGTH CALCULATED FROM 9 VARIABLES

12(b) ENGINE LENGTH CALCULATED FROM 8 VARIABLES

12(c) ENGINE LENGTH CALCULATED FROM THE THRUST RATIO
FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION (cont'd)
FIGURE 12. A TURBOJET & TURBOFAN ENGINES GEOMETRIC CORRELATION (cont'd)
13(a)
HEIGHT FOR AFTER BURNERS - 9 VARIABLES
SCALE FACTOR = 1000

PLACES OUTSIDE 10%

NO. AIRCRAFT ID

9 F100C

FIGURE 13
ENGINE CORRELATIONS BY ENGINE TYPES

13(b)
HEIGHT FOR NON-AFTER BURNERS - 9 VARIABLES
SCALE FACTOR = 100

PLACES OUTSIDE 10%

NO. AIRCRAFT ID

2 B52H
5 A10A
6 DC10-30
7 747-200
8 727-200
16 CSA
18 YA9A
21 FLMH 10
27 HND DOG
28 T39A
30 B66A
31 F86H
33 -------
13(c)
WEIGHT FOR LIGHT ENGINES - 9 VARIABLES
SCALE FACTOR = 100

13(d)
WEIGHT FOR HEAVY ENGINES - 9 VARIABLES
SCALE FACTOR = 1000

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  -------

PLANES OUTSIDE 10%
13(e)
HEIGH FOR TURBOJETS - 9 VARIABLES
SCALE FACTOR = 1000

COMPUTED

ACTUAL

13
12
11
10
9
8
7
6
5
4
3
2
1
0

PLANE OUTSIDE 10%

NO. AIRCRAFT ID

13 Boeing
24 F61D
25 FE65
27 MD DOB
26 T31A
31 FE68
33
34
35

13(f)
HEIGH FOR TURBOFANS - 9 VARIABLES
SCALE FACTOR = 100

COMPUTED

ACTUAL

90
80
70
60
50
40
30
20
10
0

PLANE OUTSIDE 10%

NO. AIRCRAFT ID

7 747-200

48
FIGURE 14. GEOMETRIC CORRELATION FOR MILITARY AIRCRAFT FROM TEKTONIX TERMINAL
TABLE I.

VEHICLES STORED IN MILITARY AIRCRAFT DATA BASE, M¹

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### TABLE IV

VEHICLES CHARACTERISTICS IN THE TRANSPORT DATA BASE, $m^2$

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### TABLE V.

**TURBOJET AND TURBOFAN DATA BASE, M³**

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## TABLE VI. ENGINE CHARACTERISTICS AVAILABLE IN ENGINE DATA BASE, M³

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TABLE VIII.

CHARACTERISTICS AVAILABLE IN THE GENERAL AVIATION LIGHT AIRCRAFT DATA BASE, \( m^4 \)

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Vehicle Gross Weight</td>
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<td>2</td>
<td>Ultimate Load Factor at Design Weight</td>
</tr>
<tr>
<td>3</td>
<td>Wing Area</td>
</tr>
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<td>Geometric Span</td>
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<td>Root Maximum Thickness</td>
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<td>Body Length</td>
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<td>Body Depth</td>
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<tr>
<td>8</td>
<td>Horizontal Tail Area</td>
</tr>
<tr>
<td>9</td>
<td>Vertical Tail Area</td>
</tr>
<tr>
<td>10</td>
<td>Payload Weight</td>
</tr>
<tr>
<td>11</td>
<td>Structural Span</td>
</tr>
<tr>
<td>12</td>
<td>Maximum Dynamic Pressure</td>
</tr>
<tr>
<td>13</td>
<td>Body Wetted Area (Approximate Value)</td>
</tr>
<tr>
<td>14</td>
<td>Thrust Per Engine</td>
</tr>
<tr>
<td>15</td>
<td>Number of Engines</td>
</tr>
<tr>
<td>MISSILE IDENTIFICATION</td>
<td>MISSILE NUMBER</td>
</tr>
<tr>
<td>------------------------</td>
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<tr>
<td>MISSILE LAUNCH WEIGHT</td>
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<tr>
<td>PAYLOAD WEIGHT, LBS.</td>
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<tr>
<td>PROPELLENT WEIGHT, LBS.</td>
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<tr>
<td>MOTOR AND NOZZLE WEIGHT, LBS</td>
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</tr>
<tr>
<td>POWER SYSTEM WEIGHT, LBS.</td>
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<tr>
<td>TAIL SURFACES WEIGHT, LBS.</td>
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<tr>
<td>AVIONICS SYSTEM WEIGHT, LBS.</td>
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<tr>
<td>BODY STRUCTURAL WEIGHT, LBS.</td>
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<td>ORIENTATION CONTROL SYSTEM WEIGHT, LBS=</td>
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<tr>
<td>LAUNCH VELOCITY, F.P.S.</td>
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<tr>
<td>LAUNCH ALTITUDE, FEET</td>
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<tr>
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<tr>
<td>PITCH INERTIA ABOUT C.G., LBS-FEET**2 =</td>
<td>16131</td>
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<td>LAUNCH/MAX. DYNAMIC PRESSURE, LB/FT**2=</td>
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<td>AVERAGE MISSILE DENSITY, LB/FT**2</td>
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<tr>
<td>S. F. C., LBS THRUST/( LBS /SEC)</td>
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<tr>
<td>EXPOSED TAIL AREA , FT**2</td>
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<tr>
<td>THRUST, LBS.</td>
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<tr>
<td>THRUST/WEIGHT</td>
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<tr>
<td>BODY PACKAGING VOLUME, FT**3</td>
<td>= 11.639</td>
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<tr>
<td>TAIL L. E. SWEEP, DEGREES</td>
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<tr>
<td>TAIL EXPOSED SPAN, FT.</td>
<td>= 1.2844</td>
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TABLE IX. TYPICAL ASM DATA BASE OUTPUT
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<tr>
<th>MISSILE IDENTIFICATION</th>
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<tbody>
<tr>
<td>TAIL ROOT CHORD, FT.</td>
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<tr>
<td>TAIL TIP CHORD, FEET</td>
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<tr>
<td>CONFIGURATION PLANFORM AREA,</td>
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<td>CONFIGURATION REF. AREA, FT.</td>
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<tr>
<td>BODY WEIGHT MULTIPLIER</td>
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<td>BODY DEPTH, FEET</td>
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<tr>
<td>BODY LENGTH, FEET</td>
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<tr>
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<td>BODY STATION NUMBER 3</td>
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<td>BODY STATION NUMBER 4</td>
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<tr>
<td>BODY STATION NUMBER 5</td>
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TABLE IX. TYPICAL ASM DATA BASE OUTPUT (cont'd)
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<td>BODY AREA NUMBER 4</td>
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<td>BODY AREA NUMBER 11</td>
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<td>BEGIN POWER SYSTEM AT STATION</td>
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<td>BEGIN PROPELLENT SECTION AT STATION</td>
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<td>CROSS RANGE, N.M.</td>
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<td>SECOND CONTROL PARAMETER</td>
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TABLE IX. TYPICAL ASM DATA BASE OUTPUT (CONCLUDED)
TABLE X. ENGINE WEIGHT ESTIMATING RELATIONSHIPS

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<th>Type</th>
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<tr>
<td>Large engines</td>
<td>E = m \times T</td>
<td>*Indicates 6000 pounds of thrust</td>
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<tr>
<td>Small engines</td>
<td>E = m \times T</td>
<td>Subscript 35 indicates 35 engine data base used</td>
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**Prime** indicates length not used in weight estimating relationship.
REFERENCES


