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Volume II - User's Guide and Model Development

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DEVELOPMENT OF NAVY AIRCRAFT BASELINE RELIABILITY PREDICTION MODELS

VOLUME II - USER'S GUIDE AND MODEL DEVELOPMENT

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Models were developed for prediction of baseline reliability characteristics of notional (conceptual) Navy fixed wing and rotary wing aircraft. Each model consists of a set of mathematical equations relating two-digit Work Unit Code subsystem Mean Flight Hours Between Failures (MFHBF) to aircraft design/performance parameters. The prediction equations were derived using MFHBF data and aircraft design/performance parameters from each of 43 representative historical Navy aircraft. Candidate predictor variables consisted of 101 design/

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20 performance parameters for fixed wing aircraft and 89 design/performance parameters for rotary wing aircraft.

This report contains two volumes:

Volume I - Executive Summary and
Volume II - User's Guide and Model Development.

A summary of development of the baseline reliability prediction models is presented in Volume I. The models and application procedure are contained in Part I of Volume II, User's Guide, while data base development, technical approach, and model validation appear in Part II.

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PREFACE

This final Technical Report on Development of Baseline Reliability Prediction Models study was prepared by the Reliability Engineering Group of the Vought Corporation, Dallas, Texas under Contract No. N00019-79-C-0355 for the Naval Air Systems Command, Washington, D. C. The objective of the study was to develop mathematical models which would permit prediction/evaluation of the reliability characteristics of notional Navy aircraft based only on the aircraft design/performance parameters.

The contract was issued on 27 April 1979 by Naval Air Systems Command (NAVAIR), Washington, D. C. Mr. Steve Meek (PMA 2694) was technical contract monitor. The contract period from 27 April through 27 October 1979 covered development of the Baseline Reliability Prediction Model for fixed wing aircraft. An interim report covering this period was submitted to NAVAIR on 27 October 1979. The contract was modified as a result of NAVAIR's exercise of a proposal option. The contract period was extended through 27 February 1980 to provide for development of the Baseline Reliability Prediction Model for rotary wing aircraft. The final report covers the entire period of contract performance from 27 April 1979 to 27 February 1980.

Messrs. Steve Meek (PMA 2694), John Zell (AIR 5185), Dave McGoy (AIR 5185), and Alek Gacic (AIR 5185) provided technical consultation and assistance in acquisition of required data, which contributed significantly to the successful completion of this study. Comments received from NAVAIR's review of the interim report contributed to the final report. Mr. Mike Waltz at the Naval Aviation Logistics Center (NALC) provided valuable suggestions/comments from his review of the interim report and final report draft.

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1. INTRODUCTION

This volume is the second of a two-volume report presenting the results of a study to develop mathematical models for predicting baseline reliability characteristics of notional (conceptual) Navy aircraft. The term "baseline" is defined as descriptive of reasonable expectations based on reported operational trends unless significant design or procedural influences are applied to effect improvements.

1.1 Objective. The objective of this study was to develop a model, i.e., a set of mathematical equations, for predicting the baseline Mean Flight Hours Between Failures (MFHBF) of notional fixed wing aircraft, and a similar model for predicting the baseline MFHBF of notional rotary wing aircraft.

To accomplish this objective, models were required which would accommodate notional aircraft design/performance parameters. In particular, the models would be capable of predicting baseline MFHBF of notional aircraft being considered by the Navy in the Sea Based Air Master Study effort. These predictions would of necessity be based on aircraft design/performance parameters progressively definitized as a part of notional aircraft evolution and assessment.

1.2 Historical Background. The increased emphasis on reliability has resulted in an increased need for a method of evaluating the reliability characteristics of notional Navy aircraft. Standard reliability prediction methods, e.g., MIL HDBK 217, cannot be used because the level of system detail is not available for a notional aircraft. However, the values of aircraft design/performance parameters can generally be obtained. Therefore, prediction of notional aircraft reliability characteristics can be predicted on the basis of aircraft design/performance parameters.

This approach has been taken in developing models for predicting maintainability and maintenance characteristics of notional aircraft (References 1 and 2). Predictions of notional aircraft maintainability and maintenance characteristics were made on the basis of equations which were developed by statistically relating historical maintenance data, at the two-digit Work Unit Code (WUC) subsystem level, to aircraft design characteristics.

This approach was taken in developing the aircraft Baseline Reliability Prediction Models. The reliability parameter used to describe the reliability characteristics of notional aircraft was Mean Flight Hours Between Failures (MFHBF). Two-digit WUC subsystem MFHBF was related statistically to historical Navy aircraft design/performance parameters.

1.3 Model Description and Application. The Baseline Reliability Prediction Models for Navy notional aircraft provide the capability of treating reliability as a conceptual aircraft trade-off parameter. The models consist of 75 statistically derived equations using notional design/performance parameters; 40 equations for fixed wing aircraft and 35 equations for rotary wing aircraft. As soon as the design/performance parameters of a notional aircraft are definitized, the baseline MFHBF can be predicted using the appropriate model. The baseline MFHBF is predicted at the two-digit WUC subsystem level of a notional aircraft. These predicted values of the MFHBF are combined mathematically to obtain the baseline MFHBF prediction of the overall notional aircraft. It should be noted that the first equation in each model was developed to predict an overall weapon system baseline MFHBF and should be used as a check or validation of the MFHBF resulting from combining the individual two-digit WUC subsystem MFHBF values.

The Baseline Reliability Prediction Models are applicable, with few constraints, to assessment of baseline MFHBF of notional Navy aircraft due to (1) the prediction equations being developed at the two-digit WUC subsystem level and (2) the wide variety of aircraft types and mission variants used for model development. In particular, these models are applicable to the notional aircraft being evaluated by the Navy as a part of the Sea Based Air Master Study (SBAMS) effort. More specifically, the fixed wing reliability prediction model is applicable to V/STOL, STOL, CTOL, and STOVL notional aircraft categories and fighter (F), attack (A), electronic warfare (EW), reconnaissance (RECCE), antisubmarine/antisurface warfare (ASW/ASUW), airborne early warning (AEW), carrier on board (COD), vertical on board (VOD), tanker (TKR), and missileer (AAW) mission variants. The rotary wing reliability prediction model is applicable to V/STOL aircraft with rotary wing characteristics and HELO notional aircraft, and ASW, marine assault (MA), VOD, and search and rescue (SAR) mission variants.

1.4 Approach. The Baseline Reliability Prediction Models were developed by application of statistical methods to derive mathematical relationships between MFHBF and selected historical aircraft design/performance parameters. An equation which relates the MFHBF of the subsystem to the aircraft design/performance parameters was developed for each two-digit WUC subsystem considered. One model, i.e., set of MFHBF prediction equations, was developed for fixed wing aircraft and another model for rotary wing aircraft. Each model was developed so that it would be applicable to different mission variants.

Three major tasks were required to develop the Navy aircraft baseline reliability prediction equations: (1) selection, extraction, and compilation of historical Navy aircraft design/performance parameters, (2) development of a reliability data base consisting of MFHBF values for each selected historical Navy aircraft at the two-digit Work Unit Code (WUC) level, and (3) model development and validation by application of statistical methods to the data bases.

1.5 Organization of Report. The remainder of this volume is divided into two major parts -- the User's Guide consisting of Sections 2 and 3, and the Model Development consisting of Sections 4 through 7. Section 2 presents two models, i.e., sets of mathematical equations, one for fixed wing and another for rotary wing aircraft application. A summary of the design/performance parameters and the historical aircraft used to derive each equation are given in Section 2. The procedures for proper application of the prediction equations are described in Section 3. Section 4 describes the selection, compilation, and screening of data for both the MFHBF Data Bases and the Design/Performance Data Bases, from which the prediction equations were derived. Section 5 presents the statistical techniques employed in the analysis of the data. Section 6 discusses in detail the procedures followed to derive the prediction models. Section 7 describes the methodology used and results of model validation efforts.

Part I
User's Guide

2. BASELINE RELIABILITY PREDICTION MODEL

Seventy-five MFHBF prediction equations were developed as elements of the two Baseline Reliability Prediction Models. Forty of the equations comprise the Fixed Wing Aircraft Prediction Model, and are presented in Section 2.2, while the remaining 35 equations were developed for the Rotary Wing Aircraft Prediction Model, and are described in Section 2.3. Prior to examination and use of the models some background as to their development will be helpful.

2.1 Equation Development. Two equation forms were considered in describing the relationships between the two-digit WUC subsystem MFHBF and the design/performance parameters of Navy aircraft. Each prediction equation has one of the following forms, depending on which form of equation provided the best fit to the data:

a. Linear - The two-digit WUC subsystem MFHBF is expressed as a linear combination of various design/performance parameters of a historical Navy aircraft, i.e., the equation is written as:

$$MFHBF = b_0 + b_1X_1 + b_2X_2 + ... + b_pX_p, \qquad (2.1)$$

where

MFHBF is mean flight hours between failures for a two-digit WUC subsystem,

$X_1, X_2, ..., X_p$ are aircraft characteristics, i.e., predictor variables and

$b_0, b_1, ..., b_p$ are constants, estimated from the data.

b. Natural Log - The natural log of the MFHBF, ln(MFHBF), is expressed as a linear combination of various aircraft characteristics, i.e., the equation is written as;

$$\ln(MFHBF) = b_0 + b_1X_1 + b_2X_2 + ... + b_pX_p = Z \qquad (2.2)$$

The MFHBF is then predicted by exponentiating the equation, i.e.,

$$MFHBF = e^{(b_0+b_1X_1 + b_2X_2 + \ldots + b_pX_p)} = e^Z \tag{2.3}$$

While Equation (2.3) is the expression used to predict the baseline MFHBF in most of the prediction equations, Equation (2.2) is the form used to perform the analysis associated with the model development.

The design/performance parameters of the prediction equations, i.e., the predictor variables, were derived through the use of a variety of selection and statistical refinement procedures (see Sections 6.1 and 6.3). While variables with intuitive appeal, from an engineering standpoint, were favored other variables, having strong statistical value, have also been included as predictor variables. Some of the seemingly unrelated variables may be acting as a proxy for more intuitive characteristics which were not included in the Design/Performance Data Base.

2.2. Fixed Wing Aircraft MFHBF Prediction Model. The Baseline Reliability Prediction Model for the fixed wing aircraft is comprised of 40 baseline MFHBF prediction equations. These equations, shown in Table 2-1, include prediction equations for each of the 38 two-digit WUC subsystems, considered basic for the fixed wing aircraft, plus two additional equations. One equation has been created to permit prediction of the overall baseline MFHBF of fixed wing aircraft and is denoted by WUC 00000. This equation was developed for use in model validation. The other equation is for predicting baseline MFHBF of either turbojet or turbofan engines, and is denoted by WUC 20000. This equation was developed to supplement the individual WUC prediction equations for WUC 23000 and WUC 27000 (see Section 6.1.2 for details).

Fixed wing aircraft design/performance parameters appearing in the prediction equations requiring a definition or explanation include:

o Type A or B:

a binary indicator parameter used to permit categorical differences between aircraft to be accounted for. For a Type A aircraft, this parameter is set equal to "0" (zero), and for a

Type B aircraft is set equal to "1" (one) Type B aircraft include fighter, attack, reconnaissance (derivatives of fighter/attack), and electronic warfare: Type A is all other aircraft. The variable is occasionally used in a product.

- Min. Combat Mission Time:
  the minimum duration of all design combat missions, excluding the ferry mission,
- Max. Ldg. Wt. -- Arrested or Design:
  the maximum arrested landing weight if the aircraft is carrier-based· the maximum design landing weight if the aircraft is land-based.
- Crew Size -- Cockpit or Total:
  cockpit crew size if the aircraft is Type B; total crew size if the aircraft is Type A.
- Kinetic Energy (multi. of 100,000):
  the (Maximum Landing Weight in Lbs) times the (Landing Sink Speed -- Limit in $ft/sec)^2$, i.e., KE = (Wt in Lbs.) times (Speed in $Ft./Sec.)^2$. Then KE is divided by 100,000 prior to use in a prediction equation. This is a modified definition and should not be confused with the standard definition in a physics text.
- Afterburner Indicator:
  a binary indicator parameter used to permit differences between aircraft, with or without an afterburner, to be accounted for. The parameter has a value of "1" when the aircraft has an afterburner, otherwise it has a value of "0".
- EW Indicator:
  a binary indicator parameter used to account for differences between electronic warfare aircraft and non-electronic warfare aircraft. The parameter has a value of "1" when the aircraft is an electronic warfare aircraft, otherwise it has a value of "0".

Additional definitions and explanations for specific fixed wing aircraft design/performance parameters are provided in Table A-6 of Appendix A and all ign/performance parameters with their units are given in Table A-8.

The predicted values for WUC 20000 (Turbojet/Turbofan Engines), WUC 22000 ...oshaft Engines), WUC 23000 (Turbojet Engines), WUC 27000 (Turbofan ...ines), and WUC 29000 (Power Plant Installation), apply to a single engine

TABLE 2-1

OVERALL FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

(WUC 00000)

$$MFHBF = 1.53255 + \sum_{i=1}^{7} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Maximum Aircraft Height	$.30591 \times 10^{-1}$
2	Fuselage Wetted Area	$.79922 \times 10^{-3}$
3	Wing Area	$-.18001 \times 10^{-2}$
4	Number of External Store Stations	$.48897 \times 10^{-1}$
5	Number of Internal Tanks	$-.70972 \times 10^{-1}$
6	Flight Design Weight	$-.19398 \times 10^{-4}$
7	Type A or B	$-.12830$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AIRFRAME

(WUC 11000)

$$Z = \ln(\text{MFHBF}) = 3.90037 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristics X_i		Coefficient b_i
1	Wing Span -- Folded (X_8)	X_8	$.45925 \times 10^{-1}$
2	Max. Aircraft Length (X_{10})	X_{10}	$-.47705 \times 10^{-1}$
3	Fuselage Volume (X_{16})	X_{16}	$-.21737 \times 10^{-3}$
4	Flight Control Surface Area (X_{19})		$-.28539 \times 10^{-3}$
5	Kinetic Energy (X_{62})		$-.44285 \times 10^{-3}$
6	Total Fuel Capacity (X_{26})		$.22795 \times 10^{-4}$
7	Max. Wing Loading (X_{35})		$-.80609 \times 10^{-2}$
8	Max. Thrust to Max Take-Off Weight (X_{61})		1.00835
9	Flight Design Wt. to Max. T.O. Weight (X_{58})		$.42445 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FUSELAGE COMPARTMENTS

(WUC 12000)

$$Z = \ln(\text{MFHBF}) = 6.26009 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Fuselage Volume (X_{16})	$.31073 \times 10^{-3}$
2	Pressurized Fuselage Volume (X_{21})	$-.39154 \times 10^{-3}$
3	Total ECS Weight (X_{24})	$.42298 \times 10^{-3}$
4	Kinetic Energy (X_{62})	$-.30346 \times 10^{-2}$
5	No. of Internal Tanks (X_{28})	-.11206
6	Max. Thrust to Max. Take-Off Weight (X_{61})	-.27330
7	Min. Combat Mission Time (X_{39})	$-.15924 \times 10^{-1}$
8	Max. Speed -- Mach No. (X_{41})	-.16122
9	Flight Design Wt. to Max. T.O. Weight (X_{58})	-1.98593

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE LANDING GEAR

(WUC 13000)

$$Z = \ln(\text{MFHBF}) = 3.74917 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Aircraft Length (X_{10})	$-.34022 \times 10^{-1}$
2	Max. Aircraft Height (X_{11})	$.57675 \times 10^{-1}$
3	Wheelbase (X_{12})	$-.22754 \times 10^{-1}$
4	Fuselage Volume (X_{16})	$-.24390 \times 10^{-3}$
5	Kinetic Energy (X_{62})	$-.18810 \times 10^{-2}$
6	Max. Ldg. Wt. -- Arrested or Design (X_{33})	$.36539 \times 10^{-4}$
7	Min. Combat Mission Time (X_{39})	$-.12237$
8	Type A or B (X_{53})	$-.34138$
9	(Min. Combat Mission Time) x (Type A or B) (X_{55})	$.10543 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FLIGHT CONTROLS

(WUC 14000)

$$Z = \ln(\text{MFHBF}) = 3.00745 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Moveable Flt. Control Surfaces	$.26782 \times 10^{-1}$
2	No. of Variable Inlets	$-.15937$
3	Wing Sweep at 1/4 Chord	$-.70022 \times 10^{-2}$
4	No. of Wing Plus Tail Folds	$.72991 \times 10^{-1}$
5	Aspect Ratio	$.34615 \times 10^{-1}$
6	Flight Control Surface Area	$-.68313 \times 10^{-3}$
7	Total ECS Weight	$-.32656 \times 10^{-3}$
8	No. of Engines	$-.83656 \times 10^{-1}$
9	Max. Wing Loading	$.30344 \times 10^{-3}$
10	Mil. Thrust to Design Weight	$-.34316 \times 10^{-2}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TURBOJET/TURBOFAN ENGINES

(WUC 20000)

$$\text{MFHBF (per engine)} = 41.29953 + \sum_{i=1}^{9} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Wing Area	$-.39357 \times 10^{-1}$
2	Engine Weight Installed Per Engine	$-.92293 \times 10^{-2}$
3	Max. Compression Ratio	.97483
4	Spec. Fuel Consumption	-10.80333
5	Turbine Inlet Temperature	$.32736 \times 10^{-2}$
6	Empty Weight	$.29245 \times 10^{-3}$
7	Max. Thrust to Inst. Eng. Weight	-3.36498
8	Min. Combat Mission Time	7.47626
9	Max. Speed -- Mach No.	17.75216

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TURBOSHAFT ENGINES

(WUC 22000)

$$\text{MFHBF (per engine)} = -43.59505 + \sum_{i=1}^{4} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Wing Area	$.26287 \times 10^{-1}$
2	Specific Fuel Consumption	-47.41315
3	Max. Thrust to Installed Engine Wt.	21.03649
4	Max. Speed -- Mach No.	101.37260

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TURBOJET ENGINES

(WUC 23000)

$$\text{MFHBF (per engine)} = 4.16807 + \sum_{i=1}^{7} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Wing Area	$-.58333 \times 10^{-1}$
2	Total Aircraft Thrust -- Military	$.10953 \times 10^{-2}$
3	Max. Engine Diameter	$.69506 \times 10^{-1}$
4	Specific Fuel Consumption	-11.54031
5	Max. Rate of Climb at Sea Level	$-.62785 \times 10^{-4}$
6	Max. Thrust to Installed Engine Wt.	8.02291
7	Min. Combat Mission Time	7.64590

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AUXILIARY POWER PLANT AIRBORNE

(WUC 24000)

$$Z = \ln(\text{MFHBF}) = 3.92959 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.73491 \times 10^{-1}$
2	Kinetic Energy	$.31667 \times 10^{-3}$
3	Max. Payload	$.90390 \times 10^{-5}$
4	Max. Combat Mission Time	$.62697 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TURBOFAN ENGINES

(WUC 27000)

$$\text{MFHBF (per engine)} = -27.07110 + \sum_{i=1}^{4} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Wing Area	$.74634 \times 10^{-1}$
2	Specific Fuel Consumption	29.39066
3	Max. Thrust to Installed Engine Wt.	.20384
4	Min. Combat Mission Time	8.29340

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE POWER PLANT INSTALLATION

(WUC 29000)

$$Z = \ln(\text{MFHBF})\ (\text{per engine}) = 4.29183 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF (per engine)} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Kinetic Energy	$.78162 \times 10^{-3}$
2	No. of Engines	$-.47342 \times 10^{-1}$
3	Max. Thrust per Engine	$-.11188 \times 10^{-3}$
4	Max. Engine Diameter	$-.43156 \times 10^{-1}$
5	Max. Engine Length	$-.66780 \times 10^{-2}$
6	Eng. Wt. Installed Per Engine	$.44121 \times 10^{-3}$
7	Max. Thrust to Installed Eng. Weight	.24905
8	Min. Combat Mission Time	.15982
9	Max. Speed -- Mach No.	.87790

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AIR CONDITIONING/PRESSURIZATION/ICE CONTROL

(WUC 41000)

$$Z = \ln(MFHBF) = 4.27794 + \sum_{i=1}^{9} b_i X_i$$

$$MFHBF = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	.20048
2	Pressurized Fuselage Volume	$-.23720 \times 10^{-3}$
3	Avionics Weight Installed	$-.69055 \times 10^{-4}$
4	Total Generator Electrical Power	$.14571 \times 10^{-2}$
5	Total ECS Weight	$-.46927 \times 10^{-3}$
6	No. of Engines	-.54877
7	Empty Weight	$.73377 \times 10^{-6}$
8	Max. Rate of Climb at Sea Level	$.71702 \times 10^{-4}$
9	Max. Speed -- Mach No.	-.37055

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE ELECTRICAL POWER SYSTEM

(WUC 42000)

$$Z = \ln(\text{MFHBF}) = 2.94917 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$.59141 \times 10^{-1}$
2	No. of Moveable Flt. Control Surfaces	$-.31479 \times 10^{-2}$
3	Flight Control Surface Area	$-.19133 \times 10^{-3}$
4	No. of Guns	.16676
5	Avionics Weight Installed	$-.16890 \times 10^{-5}$
6	Total Generator Electrical Power	$.62610 \times 10^{-2}$
7	Total Fuel Capacity	$-.18466 \times 10^{-5}$
8	No. of Engines	-.54102
9	Min. Combat Mission Time	$.70435 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE LIGHTING SYSTEM

(WUC 44000)

$$Z = \ln(\text{MFHBF}) = 3.69595 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.17937 \times 10^{-1}$
2	Wing Span -- Folded	$-.14467 \times 10^{-1}$
3	Max. Aircraft Length	$-.22274 \times 10^{-1}$
4	Max. Aircraft Height	$.58484 \times 10^{-1}$
5	Pressurized Fuselage Volume	$.15541 \times 10^{-4}$
6	Avionics Weight Installed	$-.21382 \times 10^{-4}$
7	Total ECS Weight	$.25966 \times 10^{-3}$
8	Kinetic Energy	$-.16067 \times 10^{-2}$
9	No. of Engines	$-.97012 \times 10^{-2}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE HYDRAULIC AND PNEUMATIC POWER

(WUC 45000)

$$Z = \ln(\text{MFHBF}) = 4.89547 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Moveable Flt. Control Surfaces	$.38953 \times 10^{-1}$
2	No. of Variable Inlets	$-.85082 \times 10^{-1}$
3	No. of Wing Plus Tail Folds	$-.19419$
4	Wing Area	$-.16896 \times 10^{-2}$
5	Flt. Control Surface Area	$.18224 \times 10^{-2}$
6	Total Aircraft Thrust -- Military	$-.86032 \times 10^{-5}$
7	Engine Wt. Installed Per Engine	$-.24596 \times 10^{-3}$
8	Max. Wing Loading	$-.15769 \times 10^{-1}$
9	Max. Rate of Climb at Sea Level	$.10115 \times 10^{-3}$
10	Min. Combat Mission Time	$.26280 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FUEL SYSTEM

(WUC 46000)

$$Z = \ln(\text{MFHBF}) = 4.47070 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Aircraft Length	$-.10740 \times 10^{-1}$
2	No. of External Store Stations	$.69307 \times 10^{-1}$
3	Fuel Capacity Max. Internal	$-.76420 \times 10^{-5}$
4	Total Fuel Capacity	$-.35719 \times 10^{-5}$
5	No. of External Tanks	$-.22514$
6	No. of Internal Tanks	$-.26701 \times 10^{-1}$
7	No. of Engines	$.20195$
8	Total Aircraft Thrust -- Military	$-.76385 \times 10^{-5}$
9	Engine Wt. Installed Per Engine	$-.1253[illegible] \times 10^{-3}$
10	Max. Combat Radius	$.41790 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE OXYGEN SYSTEMS

(WUC 47000)

$$Z = \ln(\text{MFHBF}) = 6.39195 + \sum_{i=1}^{7} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.82837 \times 10^{-1}$
2	Pressurized Fuselage Volume	$-.75657 \times 10^{-3}$
3	Total Generator Electrical Power	$.83093 \times 10^{-2}$
4	Empty Weight	$-.42179 \times 10^{-4}$
5	Min. Combat Mission Time	$-.85764 \times 10^{-1}$
6	Type A or B	-1.45235
7	(Min. Combat Mission Time) x (Type A or B)	.17160

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE MISCELLANEOUS UTILITIES

(WUC 49000)

$$Z = \ln(\text{MFHBF}) = 6.25902 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	.18175
2	Max. No. of External Armament Stores	$.66526 \times 10^{-2}$
3	Max. Aircraft Height	$-.77909 \times 10^{-1}$
4	Fuselage Wetted Area	$-.63791 \times 10^{-3}$
5	Wing Wetted Area	$.10243 \times 10^{-2}$
6	Total ECS Weight	$-.77721 \times 10^{-3}$
7	No. of Engines	-.56406
8	Max. Speed -- Mach No.	.28239
9	Type A or B	-.64934
10	(Max. Speed -- Mach No.) x (Type A or B)	.25522

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INSTRUMENTS

(WUC 51000)

$$Z = \ln(\mathrm{MFHBF}) = 3.68697 + \sum_{i=1}^{10} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	.12289
2	No. of Moveable Flt. Control Surfaces	$.47588 \times 10^{-1}$
3	No. of Variable Inlets	.33078
4	No. of Vertical Tails	$-.69253 \times 10^{-1}$
5	Max. No. of External Armament Stores	$.13270 \times 10^{-1}$
6	Total ECS Weight	$-.23291 \times 10^{-3}$
7	No. of Engines	-.66364
8	Max. Combat Radius	$-.57708 \times 10^{-3}$
9	Max. Speed -- Mach No.	$.37363 \times 10^{-1}$
10	(Max. Speed -- Mach No.) x (Type A or B)	-.41129

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FLIGHT REFERENCE

(WUC 56000)

$$Z = \ln(\text{MFHBF}) = 6.59589 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Variable Inlets	-.43436
2	Pressurized Fuselage Volume	$-.27376 \times 10^{-3}$
3	Avionics Weight Installed	$-.10979 \times 10^{-3}$
4	Total ECS Weight	$.44878 \times 10^{-3}$
5	Design Load Factor -- Subsonic	$-.63073 \times 10^{-1}$
6	Max. Wing Loading	$-.22801 \times 10^{-1}$
7	Max. Rate of Climb at Sea Level	$.91942 \times 10^{-4}$
8	Max. Thrust to Max. Take-Off Weight	-.50975
9	Max. Combat Radius	$-.17243 \times 10^{-3}$
10	Max. Speed -- Mach No.	-.13006

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INTEGRATED GUIDANCE/FLIGHT CONTROL

(WUC 57000)

$$Z = \ln(\text{MFHBF}) = 3.84565 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Moveable Flt. Control Surfaces	$.21782 \times 10^{-1}$
2	Pressurized Fuselage Volume	$-.82904 \times 10^{-4}$
3	Avionics Weight Installed	$.28876 \times 10^{-4}$
4	No. of Engines	.21503
5	Design Load Factor -- Subsonic	$-.21879 \times 10^{-3}$
6	Max. Wing Loading	$-.71315 \times 10^{-2}$
7	Max. Rate of Climb at Sea Level	$.10273 \times 10^{-3}$
8	Max. Thrust to Max. Take-Off Weight	-.66380
9	Max. Speed -- Mach No.	-.56747

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE VHF COMMUNICATIONS SYSTEM

(WUC 61000)

$$Z = \ln(\text{MFHBF}) = 4.32200 + \sum_{i=1}^{7} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Avionics Weight Installed	$-.11443 \times 10^{-3}$
2	Total ECS Weight	$-.52557 \times 10^{-3}$
3	Max. Combat Radius	$.59998 \times 10^{-3}$
4	Max. Speed -- Mach No.	.39669
5	Type A or B	-2.57308
6	(Max. Speed -- Mach No.) x (Type A or B)	.16335
7	(Avionics Wt. Installed) x (Type A or B)	$.48986 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE VHF COMMUNICATIONS SYSTEM

(WUC 62000)

$$Z = \ln(\text{MFHBF}) = 6.58800 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	1.44436
2	Fuselage Volume	$-.37156 \times 10^{-2}$
3	Total ECS Weight	$.93790 \times 10^{-2}$
4	Max. Combat Mission Time	-.40689

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE UHF COMMUNICATIONS

(WUC 63000)

$$Z = \ln(\text{MFHBF}) = 3.21447 + \sum_{i=1}^{11} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.69289 \times 10^{-1}$
2	Fuselage Volume	$.49928 \times 10^{-4}$
3	Avionics Weight Installed	$.19025 \times 10^{-4}$
4	Total ECS Weight	$.33068 \times 10^{-3}$
5	Kinetic Energy	$.87231 \times 10^{-3}$
6	Max. Wing Loading	$-.95668 \times 10^{-2}$
7	Max. Rate of Climb at Sea Level	$.94571 \times 10^{-4}$
8	Max. Service Ceiling --- 100 FPM	$-.93535 \times 10^{-5}$
9	Max. Combat Radius	$.25854 \times 10^{-3}$
10	Min. Combat Mission Time	$-.15570 \times 10^{-1}$
11	Max. Combat Mission Time	$.91245 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INTERPHONE SYSTEM

(WUC 64000)

$$Z = \ln(\text{MFHBF}) = 5.20450 + \sum_{i=1}^{8} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	-.11231
2	Pressurized Fuselage Volume	$.84585 \times 10^{-4}$
3	Avionics Weight Installed	$-.46752 \times 10^{-4}$
4	Total Generator Electrical Power	$-.39612 \times 10^{-2}$
5	Total ECS Weight	$-.10946 \times 10^{-3}$
6	Kinetic Energy	$-.32499 \times 10^{-2}$
7	Max. Combat Radius	$.26999 \times 10^{-3}$
8	Max. Speed -- Mach No.	.46557

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE IFF SYSTEMS

(WUC 65000)

$$Z = \ln(\mathrm{MFHBF}) = 4.11223 + \sum_{i=1}^{10} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.15445 \times 10^{-1}$
2	Fuselage Volume	$-.22737 \times 10^{-4}$
3	Avionics Weight Installed	$-.50592 \times 10^{-4}$
4	Total ECS Weight	$-.11893 \times 10^{-3}$
5	Kinetic Energy	$.64649 \times 10^{-4}$
6	Max. Wing Loading	$.52660 \times 10^{-2}$
7	Max. Service Ceiling -- 100 FPM	$-.99453 \times 10^{-5}$
8	Max. Combat Radius	$.29250 \times 10^{-3}$
9	Min. Combat Mission Time	$.26576 \times 10^{-1}$
10	Max. Combat Mission Time	$.91915 \times 10^{-2}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE EMERGENCY RADIO

(WUC 66000)

$$Z = \ln(\text{MFHBF}) = 2.75593 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Avionics Weight Installed	$-.10414 \times 10^{-3}$
2	Max. Wing Loading	$.21356 \times 10^{-1}$
3	Max. Service Ceiling --- 100 FPM	$.78696 \times 10^{-4}$
4	Max. Combat Radius	$-.28700 \times 10^{-3}$
5	Min. Combat Mission Time	.30361
6	Max. Combat Mission Time	-.11984
7	Max. Speed -- Mach No.	-.49971
8	Type A or B	-.30680
9	(Max. Wing Loading) x (Type A or B)	$-.15781 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE CNI INTEGRATED PACKAGE

(WUC 67000)

$$Z = \ln(\text{MFHBF}) = 7.87134 + \sum_{i=1}^{7} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.29080$
2	Pressurized Fuselage Volume	$-.17631 \times 10^{-2}$
3	Avionics Weight Installed	$.12476 \times 10^{-3}$
4	Max. Combat Radius	$.90909 \times 10^{-3}$
5	Min. Combat Mission Time	$-.44049$
6	Type A or B	-2.12936
7	(Avionics Wt. Installed) x (Type A or B)	$-.73023 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE MISCELLANEOUS COMMUNICATIONS EQUIPMENT

(WUC 69000)

$$Z = \ln(\text{MFHBF}) = 5.78196 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size	$-.13826$
2	Total ECS Weight	$-.51482 \times 10^{-3}$
3	Kinetic Energy	$-.79243 \times 10^{-2}$
4	Max. Combat Radius	$.15002 \times 10^{-2}$
5	Min. Combat Mission Time	$-.10007$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE RADIO NAVIGATION

(WUC 71000)

$$Z = \ln(\text{MFHBF}) = 1.96822 + \sum_{i=1}^{11} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	.27154
2	Fuselage Volume	$-.67026 \times 10^{-3}$
3	Avionics Weight Installed	$.55439 \times 10^{-4}$
4	Total ECS Weight	$.13373 \times 10^{-3}$
5	Kinetic Energy	$-.90908 \times 10^{-3}$
6	Max. Payload	$.54097 \times 10^{-4}$
7	Max. Wing Loading	$.16847 \times 10^{-1}$
8	Max. Service Ceiling -- 100 FPM	$.11970 \times 10^{-4}$
9	Max. Combat Radius	$-.38094 \times 10^{-3}$
10	Min. Combat Mission Time	$-.43786 \times 10^{-1}$
11	Max. Speed -- Mach No.	.23238

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE RADAR NAVIGATION

(WUC 72000)

$$Z = \ln(\mathrm{MFHBF}) = 4.93762 + \sum_{i=1}^{9} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	-.47311
2	Avionics Weight Installed	$-.17587 \times 10^{-3}$
3	Total ECS Weight	$.24890 \times 10^{-2}$
4	Max. Wing Loading	$-.11628 \times 10^{-1}$
5	Max. Service Ceiling -- 100 FPM	$.36808 \times 10^{-4}$
6	Max. Combat Radius	$-.13641 \times 10^{-2}$
7	Type A or B	-1.94966
8	(Avionics Weight Installed) x (Type A or B)	$-.14608 \times 10^{-3}$
9	(Max. Wing Loading) x (Type A or B)	$.14050 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE BOMBING NAVIGATION

(WUC 73000)

$$Z = \ln(\text{MFHBF}) = 2.94200 + \sum_{i=1}^{10} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.42222$
2	Fuselage Volume	$-.12459 \times 10^{-3}$
3	Avionics Weight Installed	$.84837 \times 10^{-4}$
4	Total ECS Weight	$.33431 \times 10^{-3}$
5	Kinetic Energy	$.69233 \times 10^{-2}$
6	Max. Payload	$-.82778 \times 10^{-4}$
7	Max. Wing Loading	$-.46557 \times 10^{-1}$
8	Max. Service Ceiling -- 100 FPM	$.13612 \times 10^{-3}$
9	Max. Combat Radius	$-.13005 \times 10^{-2}$
10	Min. Combat Mission Time	$.74790 \times 20^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE WEAPONS CONTROL

(WUC 74000)

$$Z = \ln(\mathrm{MFHBF}) = 12.23948 + \sum_{i=1}^{9} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. No. of External Armament Stores	$-.90434 \times 10^{-1}$
2	No. of Guns	-1.51854
3	Avionics Weight Installed	$-.10195 \times 10^{-2}$
4	Total Generator Electrical Power	$-.72135 \times 10^{-3}$
5	Total ECS Weight	$.30741 \times 10^{-2}$
6	Max. Payload	$-.26720 \times 10^{-3}$
7	Max. Combat Radius	$.38138 \times 10^{-3}$
8	Min. Combat Mission Time	$.11427$
9	Max. Speed -- Mach No.	-3.36561

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE WEAPON DELIVERY

(WUC 75000)

$$Z = \ln(\text{MFHBF}) = 6.82558 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$.82495 \times 10^{-1}$
2	Max. No. of External Armament Stores	$-.22067 \times 10^{-1}$
3	No. of External Stores Stations	$-.44025 \times 10^{-1}$
4	Avionics Weight Installed	$.17542 \times 10^{-3}$
5	Total Generator Electrical Power	$-.25332 \times 10^{-2}$
6	Empty Weight	$.88392 \times 10^{-5}$
7	Max. Wing Loading	$-.26834 \times 10^{-1}$
8	Min. Combat Mission Time	$-.52980 \times 10^{-1}$
9	Max. Speed -- Mach No.	$-.85694 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE ELECTRONIC COUNTERMEASURES

(WUC 76000)

$$Z = \ln(\text{MFHBF}) = 3.22679 + \sum_{i=1}^{8} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Fuselage Volume	$.44785 \times 10^{-4}$
2	Avionics Weight Installed	$-.27345 \times 10^{-3}$
3	Total Generator Electrical Power	$-.40632 \times 10^{-2}$
4	Max. Payload	$-.29996 \times 10^{-4}$
5	Max. Wing Loading	$.30274 \times 10^{-1}$
6	Max. Combat Radius	$-.11349 \times 10^{-2}$
7	Max. Speed -- Mach No.	-.60579
8	EW Indicator	-2.48563

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE PHOTOGRAPHIC/RECONNAISSANCE

(WUC 77000)

$$Z = \ln(\text{MFHBF}) = 2.28986 + \sum_{i=1}^{1} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Avionics Weight Installed	$-.54610 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE EMERGENCY EQUIPMENT

(WUC 91000)

$$Z = \ln(\text{MFHBF}) = 5.77479 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.31947 \times 10^{-1}$
2	Pressurized Fuselage Volume	$-.33393 \times 10^{-3}$
3	Empty Weight	$-.20307 \times 10^{-4}$
4	Max. Rate of Climb at Sea Level	$.12073 \times 10^{-4}$
5	Max. Service Ceiling -- 100 FPM	$.11927 \times 10^{-4}$
6	Max. Combat Radius	$-.95879 \times 10^{-4}$
7	Min. Combat Mission Time	$-.97573 \times 10^{-1}$
8	Max. Combat Mission Time	$.85882 \times 10^{-1}$
9	Max. Speed -- Mach No.	$-.55316$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE DECELERATION EQUIPMENT

(WUC 93000)

$$Z = \ln(\text{MFHBF}) = 9.54032 + \sum_{i=1}^{3} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Kinetic Energy	$.96141 \times 10^{-2}$
2	Empty Weight	$-.31140 \times 10^{-4}$
3	Max. Wing Loading	$-.50955 \times 10^{-1}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE PERSONNEL EQUIPMENT

(WUC 96000)

$$Z = \ln(\text{MFHBF}) = 8.39522 + \sum_{i=1}^{7} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristics X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	.12554
2	Fuselage Volume	$-.81776 \times 10^{-3}$
3	Pressurized Fuselage Volume	$-.80969 \times 10^{-3}$
4	Kinetic Energy	$.10085 \times 10^{-1}$
5	Max. Payload	$.16853 \times 10^{-3}$
6	Max. Service Ceiling -- 100 FPM	$-.58403 \times 10^{-4}$
7	Max. Combat Radius	$-.45104 \times 10^{-3}$

TABLE 2-1 (Cont.)

FIXED WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE EXPLOSIVE DEVICES

(WUC 97000)

$$Z = \ln(\text{MFHBF}) = 9.07624 + \sum_{i=1}^{8} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Cockpit or Total	$-.43738 \times 10^{-1}$
2	Max. No. of External Armament Stores	$.30074 \times 10^{-1}$
3	No. of External Stores Stations	$-.54453 \times 10^{-1}$
4	Total Aircraft Thrust -- Military	$-.33834 \times 10^{-4}$
5	Afterburner Indicator	$-.25673$
6	Max. Wing Loading	$-.27650 \times 10^{-2}$
7	Max. Combat Radius	$-.32029 \times 10^{-3}$
8	Max. Speed -- Mach No.	$-.82839 \times 10^{-1}$

instead of the two-digit WUC subsystem if an aircraft has more than one engine. To determine the predicted baseline MFHBF for the engine WUC subsystem, the predicted per engine baseline MFHBF must be divided by the number of engines of the notional aircraft under study.

Table 2-2 summarizes which variables of the Design/Performance Data Base for fixed wing aircraft appear in the equations of the Fixed Wing Aircraft Prediction Model. Some aircraft parameters appear in more than one of the equations. Other parameters of the Design/Performance Data Base were not chosen as final predictor variables for any of the two-digit WUC subsystems.

Table 2-3 lists the statistics associated with each of the fixed wing aircraft prediction equations. These statistics are associated with the regression techniques used to derive the equations and overall fit of each equation to the historical MFHBF for the WUC. For each equation, the associated ridge regression parameter (k), the coefficient of determination (R^2), for both the least squares solution and ridge solution, and the estimated value for the standard deviation of the corresponding predicted value ($\hat{\sigma}$) are shown. The significance of these values is discussed in detail in Sections 5.2 and 5.6.

These statistics apply to equations of the form

$$Y = b_0 + b_1X_1 + \dots + b_pX_p \qquad (2.4)$$

where Y = MFHBF or Y = ln(MFHBF), as appropriate. For baseline MFHBF prediction equations in the form of Equation (2.3), it should be remembered that the equation was derived using the form of Equation (2.2). So, for these equations, the estimated standard deviation, $\hat{\sigma}$, for example, is the estimated standard deviation of the ln(MFHBF), not of the MFHBF.

Ridge regression was used to derive most of the coefficients of the baseline MFHBF prediction equations. Associated with each ridge solution is the ridge parameter, k. The k-values chosen for many equations were larger than the k-values required to merely stabilize the coefficients of the

TABLE 2-2. DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
Crew Size -- Cockpit or Total									X			X	X	X			X	X	X		
No. of Move. Flt. Cont. Surf.					X								X		X				X		X
No. of Fixed Inlets																					
No. of Variable Inlets					X										X				X	X	
No. of Vertical Tails																			X		
Wing Sweep at 1/4 Chord					X																
Max. No. of Ext. Arm. Stores																		X	X		
Landing Sink Speed -- Limit																					
Tail Span																					
Wing Span -- Unfolded																					
Wing Span -- Folded		X												X							
No. of Wing Plus Tail Folds					X										X						
Max. Aircraft Length		X		X										X		X					
Max. Aircraft Height	X			X										X				X			
Mean Aerodynamic Chord																					
Wheelbase				X																	
Main Gear Tread																					
Fuse. Wetted Area	X																	X			
Wing Wetted Area																		X			

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH WUC 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
Wing Area	X					X	X	X		X					X						
Total Wetted Area																					
Fuselage Volume		X	X	X																	
Aspect Ratio					X																
No. of Ext. Store Stations	X															X					
Flt. Control Surf. Area		X			X								X		X						
Gun weight																					
No. of Guns													X								
Pres. Fuselage Volume			X									X		X			X			X	X
Avionics Wt. Installed												X	X	X						X	X
Avionics Wt. Uninstalled																					
(Min. Time: S.L. to 30K Ft)^2																					
Aux. Power Unit																					
Total Generator Elec. Power												X	X				X				
Total ECS Weight			X		X							X		X				X	X	X	
Kinetic Energy		X	X	X					X		X			X							
Fuel Cap. Int. Wing																					
Fuel Cap. Int. Fuse.																					
Fuel Cap. Ext. Tanks																					

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH WUC 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
Fuel Cap. Max. Int.																X					
Total Fuel Capacity		X											X			X					
No. of Ext. Tanks																X					
No. of Int. Tanks	X		X													X					
No. of Engines					X						X	X	X	X		X		X	X		X
Max. Thrust per Engine											X										
Total Aircraft Thrust -- Mil.								X							X	X					
Afterburner Indicator																					
Max. Engine Diameter								X			X										
Max. Eng. Length											X										
Eng. Wt. Inst. per Eng.						X					X				X	X					
No. of Fan Plus Comp. Stages																					
No. of Turbine Stages																					
Max. Compression Ratio						X															
Spec. Fuel Consumption						X	X	X		X											
Turbine Inlet Temp.						X															
Empty Weight						X						X					X				
Flight Design Weight	X																				
Design Load Factor -- Subsonic																				X	X

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH WUC 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
Max. T.O. Wt. -- Cat. or Norm																					
Max. Ldg. Wt. -- Arr. or Design				X																	
Max. Payload									X												
Bypass Ratio																					
Max. Wing Loading		X			X										X					X	X
Max. Rate of Climb at S.L.								X				X			X					X	X
Min. Time: S.L. to 30K Ft.																					
Max. Serv. Ceil. -- 100 FPM																					
Max. Thrust to Instl. Eng. Wt.						X	X	X		X	X										
Max. Thrust to Max. T.O. Wt.		X	X																	X	X
Max. Thrust to Max. Ldg. Wt.																					
Max. Combat Radius																X			X	X	
Min. Combat Mission Time			X	X		X		X		X	X		X		X		X				
Max. Combat Mission Time									X												
Max. Speed -- Mach No.			X			X	X				X	X						X	X	X	X
Min. Stall Speed -- App. Pwr.																					
Min. Ldg. Distance																					
Max. Speed at S.L.																					
Reconn. Indicator																					
EW Indicator																					

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH WUC 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
Date of 1st Flt. -- Proto.																					
Date of 1st Flt. -- Series																					
(Total Fuel Capacity)[2]																					
(Fuel Cap. Ext. Tanks)[2]																					
No. of Engine Parts																					
A/C Carrier or Land Based																					
Min. Time: S.L. to 20K Ft.																					
(Min. Time: S.L. to 20K Ft.)[2]																					
Flt. Design Wt. to Max. T.O. Wt.		X	X																		
Mil. Thrust to Design Wt.					X																
Max. Thrust or SHP to Eng. Wt. Uninst.																					
Specific Thrust or SHP																					
Max. Airflow																					
Max. Pressure Ratio																					
Fuel to Air Ratio																					
Eng. Wt. Uninst. per Eng.																					
Max. Thrust or SHP per Eng.																					
Type A or B	X			X													X	X			

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 00000 THROUGH WUC 57000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	20000	22000	23000	24000	27000	29000	41000	42000	44000	45000	46000	47000	49000	51000	56000	57000
(Max. Rate of Climb) X																					
(Type A or B)																					
(Max. Speed -- Mach No.) X																		X	X		
(Type A or B)																					
(Max. Speed at S.L.) X																					
(Type A or B)																					
(Min. Combat Mission Time) X				X													X				
(Type A or B)																					
(Avionics Wt. Inst.) X																					
(Type A or B)																					
(Max. Wing Loading) X																					
(Type A or B)																					

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
Crew Size -- Cockpit or Total		X	X	X	X		X	X	X	X	X		X			X		X	X
No. of Move. Flt. Cont. Surf.																			
No. of Fixed Inlets																			
No. of Variable Inlets																			
No. of Vertical Tails																			
Wing Sweep at 1/4 Chord																			
Max. No. of Ext. Arm. Stores													X						X
Landing Sink Speed -- Limit																			
Tail Span																			
Wing Span -- Unfolded																			
Wing Span -- Folded																			
No. of Wing Plus Tail Folds																			
Max. Aircraft Length																			
Max. Aircraft Height																			
Mean Aerodynamic Chord																			
Wheelbase																			
Main Gear Tread																			
Fuse. Wetted Area																			
Wing Wetted Area																			

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
Wing Area																			
Total Wetted Area																			
Fuselage Volume		X	X		X				X		X			X				X	
Aspect Ratio																			
No. of Ext. Store Stations												X	X						X
Flt. Control Surf. Area																			
Gun Weight																			
No. of Guns												X							
Pres. Fuselage Volume				X			X									X		X	
Avionics Wt. Installed	X		X	X	X	X	X		X	X	X	X	X	X	X				
Avionics Wt. Uninstalled																			
(Min. Time: S.L. to 30K Ft)^2																			
Aux. Power Unit																			
Total Generator Elec. Power				X								X	X	X					
Total ECS Weight	X	X	X	X	X			X	X	X	X	X							
Kinetic Energy			X	X	X			X	X		X						X	X	
Fuel Cap. Int. Wing																			
Fuel Cap. Int. Fuse.																			
Fuel Cap. Ext. Tanks																			

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
Fuel Cap. Max. Int.																			
Total Fuel Capacity																			
No. of Ext. Tanks																			
No. of Int. Tanks																			
No. of Engines																			
Max. Thrust per Engine																			
Total Aircraft Thrust -- Mil.																			X
Afterburner Indicator																			X
Max. Engine Diameter																			
Max. Eng. Length																			
Eng. Wt. Inst. per Eng.																			
No. of Fan Plus Comp. Stages																			
No. of Turbine Stages																			
Max. Compression Ratio																			
Spec. Fuel Consumption																			
Turbine Inlet Temp.																			
Empty Weight													X			X	X		
Flight Design Weight																			
Design Load Factor -- Subsonic																			

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
Max. T.O. Wt. -- Cat. or Norm																			
Max. Ldg. Wt. -- Arr. or Design																			
Max. Payload									X		X	X		X				X	
Bypass Ratio																			
Max. Wing Loading			X		X	X			X	X	X		X	X		X	X		X
Max. Rate of Climb at S.L.			X																
Min. Time: S.L. to 30K Ft.																			
Max. Serv. Ceil. -- 100 FPM			X		X	X			X	X	X					X		X	
Max. Thrust to Instl. Eng. Wt.																			
Max. Thrust to Max. T.O. Wt.																			
Max. Thrust to Max. Ldg. Wt.																			
Max. Combat Radius	X		X	X	X	X	X	X	X	X	X	X	X	X		X		X	X
Min. Combat Mission Time			X		X	X	X	X	X		X	X				X			
Max. Combat Mission Time		X	X		X	X										X			
Max. Speed -- Mach No.	X			X		X			X			X	X	X		X			X
Min. Stall Speed -- App. Pwr.																			
Min. Ldg. Distance																			
Max. Speed at S.L.																			
Reconn. Indicator																			
EW Indicator													X						

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
Date of 1st Flt. -- Proto.																			
Date of 1st Flt. -- Series																			
(Total Fuel Capacity)[2]																			
(Fuel Cap. Ext. Tanks)[2]																			
No. of Engine Parts																			
A/C Carrier or Land Based																			
Min. Time: S.L. to 20K Ft.																			
(Min. Time: S.L. to 20K Ft.)[2]																			
Flt. Design Wt. to Max. T.O. Wt.																			
Mil. Thrust to Design Wt.																			
Max. Thrust or SHP to Eng. Wt. Uninst.																			
Specific Thrust or SHP																			
Max. Airflow																			
Max. Pressure Ratio																			
Fuel to Air Ratio																			
Eng. Wt. Uninst. per Eng.																			
Max. Thrust or SHP per Eng.																			
Type A or B	X					X	X			X									

TABLE 2-2 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT -- WUC 61000 THROUGH WUC 97000

FIXED WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	61000	62000	63000	64000	65000	66000	67000	69000	71000	72000	73000	74000	75000	76000	77000	91000	93000	96000	97000
(Max. Rate of Climb) X (Type A or B)																			
(Max. Speed -- Mach No.) X (Type A or B)	X																		
(Max. Speed at S.L.) X (Type A or B)																			
(Min. Combat Mission Time) X (Type A or B)																			
(Avionics Wt. Inst.) X (Type A or B)	X						X			X									
(Max. Wing Loading) X (Type A or B)						X				X									

TABLE 2-3. FIXED WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION STATISTICS

WUC	k	R^2 Least Squares	R^2 Ridge	$\hat{\sigma}$
00000	.0115	.920	.917	.12402
11000.	.0269	.762	.735	.30223
12000	.0815	.735	.712	.39860
13000	.0145	.739	.711	.21703
14000	.1474	.650	.608	.30738
20000	.0352	.812	.785	7.74773
22000	.2115	.791	.724	18.68443
23000	.0467	.725	.667	7.92994
24000	.0125	.991	.987	.04648
27000	.0000	.993	.993	2.39502
29000	.0200	.743	.667	.38825
41000	.0462	.697	.664	.42386
42000	.0983	.473	.419	.51582
44000	.0000	.668	.668	.23914
45000	.0353	.823	.801	.31774
46000	.0510	.643	.607	.42948
47000	.0125	.839	.802	.28290
49000	.0274	.895	.887	.26560
51000	.0457	.617	.563	.37214
56000	.0778	.672	.633	.66588
57000	.1232	.604	.548	.50988
61000	.0150	.946	.864	.33922
62000	.0433	.820	.673	2.66338
63000	.0467	.549	.493	.46749
64000	.1259	.436	.389	.93979
65000	.1795	.369	.324	.50729
66000	.0175	.791	.718	.46989
67000	.0194	.667	.616	1.37011
69000	.0694	.760	.676	.82418
71000	.1482	.565	.491	.92141
72000	.0103	.680	.644	.86709
73000	.1099	.685	.606	1.04451
74000	.0141	.877	.845	1.00002
75000	.1454	.704	.649	.54727
76000	.0232	.929	.917	.49293
77000	.0000	.665	.665	.72942
91000	.1585	.717	.691	.49039
93000	.0000	.952	.952	.16263
96000	.0548	.856	.835	.59665
97000	.1724	.596	.563	.61370

equation when extrapolation of an aircraft's design/performance parameters may be required for prediction of notional aircraft baseline MFHBF. Thus, the associated ridge R^2's are reduced accordingly. To more properly measure the prediction equations' fit to the data, the R^2 of the least squares version of the prediction equation is also shown. Since a ridge solution with a k-value equal to zero is the least squares solution, when the least squares coefficients have been used, the value of k is zero and both R^2's are equal (see Section 5.6 for details).

Table 2-4 shows the aircraft, as identified by their primary mission variants, used in the development of each prediction equation. While, in general, all applicable carrier-based aircraft were used, the use of the land-based aircraft was restricted to those WUC's where data from only a few aircraft was available to derive an equation. For WUC 62000 and WUC 73000, only historical fighter, attack, reconnaissance, and electronic warfare aircraft were used to develop the prediction equation. These aircraft formed a more homogeneous group than the group of all fixed wing aircraft, thereby permitting the development of a better prediction equation for these WUC's. In the case of WUC 77000, only reconnaissance aircraft were used to develop the prediction equation. As this WUC has little impact on the overall reliability of other types of aircraft (i.e., few failures are reported against this WUC relative to the total number of flight hours of the aircraft), the inclusion of the remaining aircraft distorted the predicted baseline MFHBF of the reconnaissance aircraft. The KC-130R was omitted from the data base in developing an equation for WUC 22000. The unexplainably large value for the MFHBF made development of a good prediction equation difficult. With only eight aircraft available for deriving the equation for WUC 22000, this single value dominated the development of a baseline MFHBF prediction equation.

2.3 Rotary wing Aircraft MFHBF Prediction Model. Thirty-five baseline MFHBF prediction equations form the Baseline Reliability Prediction Model for rotary wing aircraft. These equations presented in Table 2-5, include 34 equations which permit prediction of baseline MFHBF of two-digit WUC subsystems. The remaining equation, denoted by WUC 00000 and developed for model validation, permits prediction of the overall baseline MFHBF of rotary

TABLE 2-4. HISTORICAL AIRCRAFT USED FOR DEVELOPMENT OF BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT

WUC	DESCRIPTION	CARRIER BASED								LAND BASED	
		FIGHTER	ATTACK	RECCE	EW	AEW	ASW	COD	TANKER	PATROL ASW	TANKER
00000	Overall Aircraft	X	X	X	X	X	X	X	X		
12000	Fuselage Compartments	X	X	X	X	X	X	X	X		
13000	Landing Gear	X	X	X	X	X	X	X	X		
14000	Flight Controls	X	X	X	X	X	X	X	X		
20000	Turbojet/ Turbofan Eng.	X	X	X	X		X		X		
22000	Turboshaft Engines					X		X		X	X
23000	Turbojet Engines	X	X	X	X				X		
24000	Aux. Power Plant Airborne						X	X		X	X
27000	Turbofan Engines	X	X				X				
29000	Power Plant Installation	X	X	X	X	X	X	X	X		
41000	Air Cond/Pres/ Ice Control	X	X	X	X	X	X	X	X		
42000	Elec. Power Sys	X	X	X	X	X	X	X	X		

TABLE 2-4 (Cont.) HISTORICAL AIRCRAFT USED FOR DEVELOPMENT OF BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT

WUC	DESCRIPTION	CARRIER BASED								LAND BASED	
		FIGHTER	ATTACK	RECCE	EW	AEW	ASW	COD	TANKER	PATROL ASW	TANKER
44000	Lighting System	X	X	X	X	X	X	X	X		
45000	Hydraulic and Pneumatic Pwr.	X	X	X	X	X	X	X	X		
46000	Fuel System	X	X	X	X	X	X	X	X		
47000	Oxygen System	X	X	X	X	X	X	X	X		
49000	Misc. Utilities	X	X	X	X	X	X	X	X		
51000	Instruments	X	X	X	X	X	X	X	X		
56000	Flight Reference	X	X	X	X	X	X	X	X		
57000	Int. Guidance/ Flt. Control	X	X	X	X	X	X	X	X		
61000	HF Comm. Sys.				X	X	X	X	X	X	X
62000	VHF Comm. Sys.	X	X	X	X						
63000	UHF Comm. Sys.	X	X	X	X						
64000	Interphone Sys.	X	X	X	X	X	X	X	X	X	X
65000	IFF Systems	X	X	X	X	X	X	X	X	X	X
66000	Emergency Radio	X	X	X	X	X	X	X	X	X	X
67000	CNI Int. Package	X	X	X	X	X	X	X	X	X	X
69000	Misc. Comm. Equipment	X	X			X	X	X		X	X

TABLE 2-4 (Cont.) HISTORICAL AIRCRAFT USED FOR DEVELOPMENT OF BASELINE MFHBF PREDICTION EQUATIONS FOR FIXED WING AIRCRAFT

		CARRIER BASED								LAND BASED	
WUC	DESCRIPTION	FIGHTER	ATTACK	RECCE	EW	AEW	ASW	COD	TANKER	PATROL ASW	TANKER
71000	Radio Navigation	X	X	X	X	X	X	X	X		
72000	Radar Navigation	X	X	X	X	X	X	X	X		
73000	Bombing Navigation	X	X	X	X						
74000	Weapons Control	X	X	X	X		X		X		
75000	Weapon Delivery	X	X	X	X	X	X	X	X		
76000	Elec. Counter-measures	X	X	X	X	X	X	X	X		
77000	Photographic/ Reconn			X							
91000	Emergency Equipment	X	X	X	X	X	X	X	X		
93000	Deceleration Equipment	X	X	X	X				X		
96000	Personnel Equipment	X	X	X	X	X	X	X			
97000	Explosive Devices	X	X	X	X		X	X	X		

wing aircraft. For WUC 22000 (Turboshaft Engines) and WUC 29000 (Power Plant Installation), the associated equation predicts the MFHBF on a per engine basis. To predict the baseline MFHBF at the two-digit WUC subsystem level, the predicted baseline MFHBF derived from the equation must be divided by the number of engines for the notional aircraft under consideration.

Rotary wing aircraft design/performance parameters requiring a definition or explanation to interpret the prediction equations include:

- Max. Take-Off or Landing Weight:
  the data available for data base development consistently showed the two parameters to be equal in value. If a situation develops where the values are different, the recommended approach is to use the larger value.

- No. of External Launch Points:
  the number of external attachment points for munitions with the exception of flares.
- MA Indicator:
  a binary indicator parameter whose value is "1" if the notional aircraft's primary mission is marine assault and is "0" if the aircraft's primary mission is not marine assault.
- Tail Pylon Fold:
  a binary indicator parameter whose value is "1" if the notional aircraft has a tail pylon fold and "0" if the aircraft does not have a folding tail.

- Total Aircraft SHP -- Mil. or Int. Power:
  the product of the number of propulsion engines and the Military or Intermediate shaft horsepower.

- Main Rotor Disc Area (Sweep):
  the area swept by one revolution of the main rotor blades.

Definitions and explanations for specific rotary wing aircraft design/performance parameters are provided in Table A-7 of Appendix A and all

TABLE 2-5

OVERALL ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

(WUC 00000)

$$MFHBF = 1.04937 + \sum_{i=1}^{5} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.32053 \times 10^{-5}$
2	No. of External Launch Points	$.13466 \times 10^{-2}$
3	Total Fuel Capacity	$.61999 \times 10^{-5}$
4	No. of Internal Tanks	$-.50664 \times 10^{-1}$
5	MA Indicator	$.49387 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AIRFRAME

(WUC 11000)

$$MFHBF = 4.72218 + \sum_{i=1}^{6} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Aircraft Length -- Operating	$-.50565 \times 10^{-1}$
2	Wheelbase	$-.38548 \times 10^{-1}$
3	Total Aircraft SHP -- Mil. Power to Max. Take-Off Weight	-47.96398
4	Main Rotor Disc Area	$-.40014 \times 10^{-3}$
5	Total Fuel Capacity	$.21651 \times 10^{-4}$
6	Max. Speed at Sea Level	$.97494 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FUSELAGE COMPARTMENTS

(WUC 12000)

$$Z = \ln(\text{MFHBF}) = 3.94821 + \sum_{i=1}^{6} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Fuselage Length -- Folded	$-.22440 \times 10^{-2}$
2	Total Aircraft SHP -- Mil. Power to Max. Take-Off Weight	-1.11013
3	Total ECS Weight	$-.82732 \times 10^{-3}$
4	No. of Internal Tanks	$.46984 \times 10^{-1}$
5	Max. Speed at Sea Level	$-.24387 \times 10^{-2}$
6	Max. Combat Radius	$.10349 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE LANDING GEAR

(WUC 13000)

$$Z = \ln(\text{MFHBF}) = 3.21700 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Fuselage Length -- Folded	$-.20672 \times 10^{-1}$
2	Fuselage Depth -- Folded	$-.23710$
3	Aircraft Height -- Operating	$.43456 \times 10^{-1}$
4	Wheelbase	$.52188 \times 10^{-1}$
5	Main Gear Tread	$.21140 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FLIGHT CONTROLS

(WUC 14000)

$$Z = \ln(\mathrm{MFHBF}) = 1.28639 + \sum_{i=1}^{4} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Main Rotor Blades	-.32187
2	No. of Tail Rotor Blades	.85119
3	Tail Pylon Fold	-.20644
4	Max. Disc Loading	$-.22336 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE HELICOPTER ROTOR SYSTEM

(WUC 15000)

$$Z = \ln(\text{MFHBF}) = .62628 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Main Rotor Gear Ratio	3.00931
2	Main Rotor Transmission Limit -- SHP	$-.82526 \times 10^{-4}$
3	Main Rotor Transmission Limit -- RPM	$-.17652 \times 10^{-4}$
4	Blade Loading	18.09090
5	Max. Disc Loading	$.61583 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TURBOSHAFT ENGINES

(WUC 22000)

$$\text{MFHBF (Per Engine)} = -\ 430.03961 + \sum_{i=1}^{4} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Empty Weight	$.32996 \times 10^{-2}$
2	Military SHP per Engine	$-.38649 \times 10^{-1}$
3	Turbine Inlet Temperature	.22618
4	Max. Speed at Sea Level	.61042

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AUXILIARY POWER PLANT AIRBORNE

(WUC 24000)

$$MFHBF = 87.42285 + \sum_{i=1}^{3} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.40076 \times 10^{-3}$
2	Crew Size -- Total	-4.66619
3	Rotor Weight	$-.14751 \times 10^{-2}$

TABLE 2-5 (Cont.)
ROTARY WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION
FOR THE HELICOPTER ROTARY WING

(WUC 26000)

$$Z = \ln(MFHBF) = 3.03532 + \sum_{i=1}^{4} b_i X_i$$

$$MFHBF = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Total Aircraft SHP -- Mil. or Int. Power	$-.25548 \times 10^{-3}$
2	Main Rotor Gear Ratio	2.13442
3	Main Rotor Transmission Limit -- SHP	$.21675 \times 10^{-3}$
4	Power Transmission Weight (Without Rotor)	$-.10116 \times 10^{-3}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE POWER PLANT INSTALLATION

(WUC 29000)

$$Z = \ln(\text{MFHBF})\ (\text{Per Engine}) = 6.27446 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF (Per Engine)} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.29660 \times 10^{-5}$
2	Military SHP per Engine	$-.11189 \times 10^{-3}$
3	Engine Weight Installed Per Engine	$.14360 \times 10^{-3}$
4	Mil. SHP per Eng. to Eng. Weight Inst. Per Engine	$.12327 \times 10^{-1}$
5	Max. Speed at Altitude	$-.17184 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE AIR CONDITIONING/PRESSURIZATION/ICE CONTROL

(WUC 41000)

$$Z = \ln(MFHBF) = 7.68804 + \sum_{i=1}^{4} b_i X_i$$

$$MFHBF = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Empty Weight	$.14056 \times 10^{-3}$
2	Total Generator Electrical Power	$-.26245 \times 10^{-1}$
3	Max. Disc Loading	$.69758 \times 10^{-3}$
4	Max. Speed at Sea Level	$-.23598 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE ELECTRICAL POWER SYSTEM

(WUC 42000)

$$Z = \ln(\text{MFHBF}) = 3.09712 + \sum_{i=1}^{6} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	$.37854 \times 10^{-2}$
2	No. of Main Rotor Blades	$-.12872$
3	Main Rotor Blade Area (Total)	$.85274 \times 10^{-3}$
4	Avionics Weight Installed	$.11380 \times 10^{-3}$
5	Total Fuel Capacity	$-.15094 \times 10^{-4}$
6	Max. Combat Range	$-.31860 \times 10^{-3}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE LIGHTING SYSTEM

(WUC 44000)

$$Z = \ln(\text{MFHBF}) = 2.48154 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.84278 \times 10^{-5}$
2	Crew Size -- Total	.11172
3	Main Rotor Radius	$.35873 \times 10^{-2}$
4	Aircraft Length -- Operating	$.37966 \times 10^{-3}$
5	Avionics Weight Installed	$.40048 \times 10^{-4}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE HYDRAULIC AND PNEUMATIC POWER SYSTEM

(WUC 45000)

$$MFHBF = -1.11821 + \sum_{i=1}^{5} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Main Rotor Blades	16.62264
2	Total Aircraft SHP -- Mil. or Int. Power	$.30987 \times 10^{-2}$
3	Main Rotor Disc Area	$-.30294 \times 10^{-1}$
4	Max. Disc Loading	2.35658
5	Vertical Rate of Climb at Sea Level -- Mil.	$.12637 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FUEL SYSTEM

(WUC 46000)

$$Z = \ln(\mathrm{MFHBF}) = 5.03895 + \sum_{i=1}^{6} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Total Aircraft SHP -- Mil. or Int. Power	$.68473 \times 10^{-4}$
2	Fuel Capacity Internal	$.16017 \times 10^{-3}$
3	Total Fuel Capacity	$-.13038 \times 10^{-4}$
4	No. of Internal Tanks	-.51304
5	No. of Auxiliary Tanks	-.18282
6	Max. Combat Radius	$-.21847 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE MISCELLANEOUS UTILITIES

(WUC 49000)

$$Z = \ln(\text{MFHBF}) = 4.50598 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	-.17640
2	Fuselage Length -- Folded	-.16904
3	Aircraft Height -- Operating	.45926
4	No. of External Launch Points	-.15755
5	Max. Speed at Sea Level	$.47586 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INSTRUMENTS

(WUC 51000)

$$Z = \ln(\text{MFHBF}) = 1.67311 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	.15689
2	No. of Main Rotor Blades	$.94185 \times 10^{-1}$
3	Max. Service Ceiling	$.13403 \times 10^{-4}$
4	Max. Combat Radius	$.10855 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE TELEMETRY

(WUC 54000)

$$Z = \ln(MFHBF) = 2.68914 + \sum_{i=1}^{2} b_i X_i$$

$$MFHBF = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Speed at Sea Level	$.71582 \times 10^{-2}$
2	Max. Combat Range	$.41961 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE FLIGHT REFERENCE

(WUC 56000)

$$Z = \ln(\text{MFHBF}) = 9.16181 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Total Aircraft SHP -- Mil. Power to Max. Take-Off Weight	10.97685
2	Avionics Weight Installed	$-.22701 \times 10^{-3}$
3	Total ECS Weight	$.18198 \times 10^{-2}$
4	Max. Disc Loading	$-.78750 \times 10^{-1}$
5	Max. Speed at Sea Level	$-.40337 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INTEGRATED GUIDANCE/FLIGHT CONTROL

(WUC 57000)

$$Z = \ln(\mathrm{MFHBF}) = 7.46684 + \sum_{i=1}^{5} b_i X_i$$

$$\mathrm{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of Main Rotor Blades	.13636
2	Blade Loading	-45.47485
3	Main Rotor Disc Area (Sweep)	$-.31591 \times 10^{-3}$
4	Max. Rate of Climb -- Normal	$-.27933 \times 10^{-3}$
5	Max. Combat Radius	$-.92787 \times 10^{-3}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE HF COMMUNICATIONS SYSTEM

(WUC 61000)

$$Z = \ln(\text{MFHBF}) = 8.90284 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.45586 \times 10^{-4}$
2	Total ECS Weight	$.59804 \times 10^{-2}$
3	Max. Speed at Sea Level	$-.29407 \times 10^{-1}$
4	MA Indicator	$-.27474$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE VHF COMMUNICATIONS

(WUC 62000)

$$Z = \ln(\text{MFHBF}) = 2.92816 + \sum_{i=1}^{3} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	.99771
2	Avionics Weight Installed	$-.13513 \times 10^{-2}$
3	Vertical Rate of Climb at Sea Level -- Military	$-.54807 \times 10^{-3}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE UHF COMMUNICATIONS

(WUC 63000)

$$Z = \ln(\text{MFHBF}) = 2.74886 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	$.52142 \times 10^{-1}$
2	Avionics Weight Installed	$.26948 \times 10^{-3}$
3	Total ECS Weight	$.11000 \times 10^{-2}$
4	Vertical Rate of Climb at Sea Level -- Mil.	$.43734 \times 10^{-3}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE INTERPHONE SYSTEM

(WUC 64000)

$$Z = \ln(\text{MFHBF}) = 1.61013 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	.10950
2	Total ECS Weight	$-.68720 \times 10^{-2}$
3	Total Generator Electrical Power	$.32186 \times 10^{-1}$
4	Max. Speed at Sea Level	$.12639 \times 10^{-1}$
5	Max. Combat Radius	$-.24535 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE IFF SYSTEMS

(WUC 65000)

$$MFHBF = 52.41107 + \sum_{i=1}^{5} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	50.67168
2	Max. Disc Loading	-8.29714
3	Max. Service Ceiling	$-.20284 \times 10^{-1}$
4	Max. Speed at Sea Level	1.95050
5	Max. Combat Radius	-.20425

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE CNI INTEGRATED PACKAGE

(WUC 67000)

$$Z = \ln(MFHBF) = 8.34850 + \sum_{i=1}^{5} b_i X_i$$

$$MFHBF = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	-.25907
2	Avionics Weight Installed	$-.70483 \times 10^{-4}$
3	Max. Disc Loading	$-.23091 \times 10^{-1}$
4	Vertical Rate of Climb at Sea Level -- Mil.	$-.76878 \times 10^{-4}$
5	Max. Speed at Sea Level	$-.63480 \times 10^{-2}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE RADIO NAVIGATION

(WUC 71000)

$$Z = \ln(\text{MFHBF}) = 1.62556 + \sum_{i=1}^{5} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.45196 \times 10^{-4}$
2	Crew Size -- Total	.22517
3	Total ECS Weight	$.49959 \times 10^{-3}$
4	Max. Disc Loading	.12123
5	Max. Service Ceiling	$.69230 \times 10^{-4}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE RADAR NAVIGATION

(WUC 72000)

$$MFHBF = -98.68611 + \sum_{i=1}^{5} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$-.95457 \times 10^{-4}$
2	Total ECS Weight	.22789
3	Max. Disc Loading	1.87081
4	Max. Service Ceiling	$-.52850 \times 10^{-3}$
5	Max. Speed at Sea Level	.77013

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE BOMBING NAVIGATION

(WUC 73000)

$$Z = \ln(\text{MFHBF}) = 6.10894 + \sum_{i=1}^{3} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	-.23964
2	Avionics Weight Installed	$-.78977 \times 10^{-3}$
3	Max. Disc Loading	-.21050

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE WEAPONS CONTROL

(WUC 74000)

$$Z = \ln(\text{MFHBF}) = 7.63492 + \sum_{i=1}^{3} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Blade Loading	-29.34114
2	Avionics Weight Installed	$-.17852 \times 10^{-4}$
3	Max. Disc Loading	$-.88480 \times 10^{-1}$

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE WEAPON DELIVERY

(WUC 75000)

$$Z = \ln(\text{MFHBF}) = 5.99483 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Crew Size -- Total	-.43164
2	No. of External Launch Points	$-.85810 \times 10^{-1}$
3	Total Generator Electrical Power	$.73377 \times 10^{-1}$
4	Max. Disc Loading	-.34748

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE ELECTRONIC COUNTERMEASURES

(WUC 76000)

$$MFHBF = 5976.50453 + \sum_{i=1}^{2} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Total ECS Weight	6.61701
2	Max. Disc Loading	-723.53388

TABLE 2-5 (Cont.)

ROTARY WING AIRCRAFT

BASELINE MFHBF PREDICTION EQUATION

FOR THE EMERGENCY EQUIPMENT

(WUC 91000)

$$MFHBF = 192.03016 + \sum_{i=1}^{5} b_i X_i$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Blade Loading	-2913.69414
2	Max. Disc Loading	14.54656
3	Vertical Rate of Climb at Sea Level -- Mil.	.20030
4	Max. Service Ceiling	$.23566 \times 10^{-1}$
5	Max. Combat Radius	-.60810

TABLE 2-5 (Cont.)
ROTARY WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION
FOR THE PERSONNEL EQUIPMENT

(WUC 96000)

$$Z = \ln(\mathrm{MFHBF}) = 4.26874 + \sum_{i=1}^{2} b_i X_i$$

$$\mathrm{MFHBF} = e^{Z}$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	Max. Take-Off or Landing Weight	$.27301 \times 10^{-4}$
2	Max. Combat Radius	$.10559 \times 10^{-1}$

TABLE 2-5 (Cont.)
ROTARY WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION
FOR THE EXPLOSIVE DEVICES

(WUC 97000)

$$Z = \ln(\text{MFHBF}) = 8.26801 + \sum_{i=1}^{4} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Variable i	Aircraft Characteristic X_i	Coefficient b_i
1	No. of External Launch Points	$.69047 \times 10^{-1}$
2	Blade Loading	86.19068
3	Max. Speed at Sea Level	$-.52060 \times 10^{-1}$
4	Max. Combat Radius	$-.34906 \times 10^{-2}$

design/performance parameters with their units are given in Table A-9.

Table 2-6 presents a summary of which variables, of the Design/Performance Data Base for rotary wing aircraft, appear in the prediction equations of the Rotary Wing Aircraft Prediction Model. Certain design/performance parameters were chosen as final predictor variables for more than one of the two-digit WUC prediction equations. Other aircraft characteristics were used in the initial development of the equation, but were not included as final predictor variables in any baseline MFHBF prediction equations.

Various statistics associated with the regression analysis, from which the prediction equation were derived, are presented in Table 2-7. The ridge regression parameter (k), the coefficient of determination (R^2), for both the least squares solution and the ridge solution, and the estimated value for the standard deviation of the corresponding predicted value ($\hat{\sigma}$) are given for each equation of the model. The significance of these statistics and the interpretation of the values are given in Section 5.

The statistics shown in Table 2-7 apply to the form of the prediction equations given in Equations (2.1) and (2.2). While Equation (2.3) is used to solve for the predicted baseline MFHBF in most cases, Equation (2.2) was the mathematical expression derived through regression analysis. Thus, the statistics are associated with the appropriate linear and natural log forms.

For most of the baseline MFHBF prediction equations, ridge regression was used to determine the values of the coefficients. Corresponding to each ridge solution is a value for the ridge parameter, k. In many cases, a relatively large value of k was chosen to gain additional stability in the coefficients. Since the oversizing of k also results in an artificially low value of R^2 for the ridge solution, the R^2 of the least squares solution is also presented. The least squares coefficient of determination is a better measure of the equation's fit to the data.

Table 2-8 indicates the aircraft, as identified by their primary mission variant, which were used to develop each rotary wing prediction equation. As only eleven rotary wing aircraft were selected for use in deriving the model, aircraft, for which three or more quarters of historical MFHBF data were

TABLE 2-6. DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Empty Weight							X				X												
Max. Take-Off or Landing Wt.	X							X		X			X								X		
Design Load Factor																							
Crew Size -- Total								X				X	X			X	X					X	X
No. of Troops																	X						
No. of Main Rotor Blades					X							X		X						X			
No. of Tail Rotor Blades					X																		
No. of Engines																							
Main Rotor Radius													X										
Tail Rotor Radius																							
Fuselage Length -- Folded			X	X									X			X							
Fuselage Depth -- Folded				X																			
Fuselage Width -- Folded																							
Aircraft Length -- Oper.		X																					
Aircraft Span -- Oper.																							
Aircraft Height -- Oper.				X												X							
Wheelbase		X		X																			
Main Gear Tread				X																			

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Main Rotor Blade Chord																							
Tail Rotor Blade Chord																							
No. of External Launch Pts.	X															X							
Max. No. of Ext. Armament Stores																							
No. of Ext. Torpedo Store Stations																							
No. of Int. Sonobuoy Stores																							
Tail Pylon Fold					X																		
Date of 1st Flt. -- Series																							
Date of 1st Flt. -- Prototype																							
Date of 1st Flt. -- Service																							
Total A/C SHP -- Mil. or Int. Power									X					X	X								
Total A/C SHP -- Normal Power																							
Military SHP per Engine							X			X													
Normal SHP per Engine																							
Total SHP -- Normal Power to Max. Take-Off Wt.																							
Max. Engine Diameter																							

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Max. Engine Length																							
Eng. Wt. Inst. per Engine										X													
No. of Fan Plus Comp. Stages																							
No. of Turbine Stages																							
Max. Compression Ratio																							
Spec. Fuel Cons. -- Mil. or Int.																							
Spec. Fuel Cons. -- Normal																							
Turbine Inlet Temp.							X																
No. of Mission Variants																							
Mil. SHP per Eng. to Eng. Wt. Inst. per Engine										X													
Total A/C SHP -- Mil. Power to Max. Take-Off Wt.		X	X																X				
No. of Engine Parts																							
Main Rotor Gear Ratio						X			X														
Main Rotor Tip Speed at Design Limit																							

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Main Rotor Trans. Limit -- SHP						X			X														
Main Rotor Trans. Limit -- RPM						X																	
Power Trans. Wt. (w/o Rotor)									X														
Rotor Weight								X															
Blade Loading						X														X			
Eng. RPM -- Mil. or Int. Power																							
Total Rotor Disc Area -- Main + Tail																							
Total Blade Area -- Main + Tail																							
Main Rotor Disc Area		X												X						X			
Tail Rotor Disc Area																							
Main Rotor Blade Area per Blade																							
Tail Rotor Blade Area per Blade																							
Main Rotor Blade Area -- Total												X											
Tail Rotor Blade Area -- Total																							
Avionics Wt. Installed												X	X						X				X
Avionics Wt. Uninstalled																							

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Total ECS Weight			X																X		X		X
Air Conditioning Weight																							
Anti-Icing Weight																							
Aux. Power Unit																							
No. of Aircraft Generators																							
Gen. Elec. Power per Gen.																							
Total Gen. Elec. Power											X												
Fuel Capacity Internal															X								
Fuel Capacity Auxiliary																							
Total Fuel Capacity	X	X										X			X								
No. of Internal Tanks	X		X												X								
No. of Auxiliary Tanks															X								
Max. Disc Loading					X	X					X			X					X				
Vert. Rate of Climb at Sea Level -- Mil.														X								X	X
Abs. Hovering Ceiling -- Mil.																							
Max. Rate of Climb -- Normal																				X			

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 00000 THROUGH WUC 63000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	00000	11000	12000	13000	14000	15000	22000	24000	26000	29000	41000	42000	44000	45000	46000	49000	51000	54000	56000	57000	61000	62000	63000
Max. Service Ceiling																	X						
Max. Speed at Sea Level		X	X				X				X					X		X	X		X		
Max. Combat Radius			X												X		X			X			
Max. Combat Range												X						X				X	
Max. Speed at Altitude										X													
Assoc. Alt. for Max. Speed																							
Avg. Cruising Speed -- Primary Mission																							
Cruising Altitude -- Primary Mission																							
MA Indicator	X																				X		

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH WUC 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Empty Weight												
Max. Take-Off or Landing Wt.				X	X						X	
Design Load Factor												
Crew Size -- Total	X	X	X	X		X		X				
No. of Troops												
No. of Main Rotor Blades												
No. of Tail Rotor Blades												
No. of Engines												
Main Rotor Radius												
Tail Rotor Radius												
Fuselage Length -- Folded												
Fuselage Depth -- Folded												
Fuselage Width -- Folded												
Aircraft Length -- Oper.												
Aircraft Span -- Oper.												
Aircraft Height -- Oper.												
Wheelbase												
Main Gear Tread												

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH WUC 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Main Rotor Blade Chord												
Tail Rotor Blade Chord												
No. of External Launch Pts.								X				X
Max. No. of Ext. Armament Stores												
No. of Ext. Torpedo Store Stations												
No. of Int. Sonobuoy Stores												
Tail Pylon Fold												
Date of 1st Flt. -- Series												
Date of 1st Flt. -- Prototype												
Date of 1st Flt. -- Service												
Total A/C SHP -- Mil. or Int. Power												
Total A/C SHP -- Normal Power												
Military SHP per Engine												
Normal SHP per Engine												
Total SHP -- Normal Power												
to Max. Take-Off Wt.												
Max. Engine Diameter												

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH WUC 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS / TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Max. Engine Length												
Eng. Wt. Inst. per Engine												
No. of Fan Plus Comp. Stages												
No. of Turbine Stages												
Max. Compression Ratio												
Spec. Fuel Cons. -- Mil. or Int.												
Spec. Fuel Cons. -- Normal												
Turbine Inlet Temp.												
No. of Mission Variants												
Mil. SHP per Eng. to Eng. Wt. Inst. per Engine												
Total A/C SHP -- Mil. Power to Max. Take-Off Wt.												
No. of Engine Parts												
Main Rotor Gear Ratio												
Main Rotor Tip Speed at Design Limit												

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH WUC 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Main Rotor Trans. Limit -- SHP												
Main Rotor Trans. Limit -- RPM												
Power Trans. Wt. (w/o Rotor)												
Rotor Weight												
Blade Loading							X			X		X
Eng. RPM -- Mil. or Int. Power												
Total Rotor Disc Area -- Main + Tail												
Total Blade Area -- Main + Tail												
Main Rotor Disc Area												
Tail Rotor Disc Area												
Main Rotor Blade Area per Blade												
Tail Rotor Blade Area per Blade												
Main Rotor Blade Area -- Total												
Tail Rotor Blade Area -- Total												
Avionics Wt. Installed			X			X	X					
Avionics Wt. Uninstalled												

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH WUC 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Total ECS Weight	X			X	X				X			
Air Conditioning Weight												
Anti-Icing Weight												
Aux. Power Unit												
No. of Aircraft Generators												
Gen. Elec. Power per Gen.												
Total Gen. Elec. Power	X							X				
Fuel Capacity Internal												
Fuel Capacity Auxiliary												
Total Fuel Capacity												
No. of Internal Tanks												
No. of Auxiliary Tanks												
Max. Disc Loading		X	X	X	X	X	X	X	X	X		
Vert. Rate of Climb at Sea Level -- Mil.			X							X		
Abs. Hovering Ceiling -- Mil.												
Max. Rate of Climb -- Normal												

TABLE 2-6 (Cont.). DESIGN/PERFORMANCE DATA BASE PARAMETERS USED IN BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT -- WUC 64000 THROUGH 97000

ROTARY WING DESIGN/PERFORMANCE PARAMETERS \ TWO-DIGIT WUC	64000	65000	67000	71000	72000	73000	74000	75000	76000	91000	96000	97000
Max. Service Ceiling		X		X	X					X		
Max. Speed at Sea Level	X	X	X		X							X
Max. Combat Radius	X	X								X	X	X
Max. Combat Range												
Max. Speed at Altitude												
Assoc. Alt. for Max. Speed												
Avg. Cruising Speed -- Primary Mission												
Cruising Altitude -- Primary Mission												
MA Indicator												

TABLE 2-7. ROTARY WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION STATISTICS

WUC	k	R^2 Least Squares	R^2 Ridge	$\hat{\sigma}$
00000	.2031	.725	.670	.05701
11000	.0075	.883	.853	.42770
12000	.2743	.871	.845	.14836
13000	.0050	.941	.883	.12562
14000	.0175	.965	.953	.15824
15000	.0168	.965	.961	.05831
22000	.0175	.965	.873	5.92555
24000	.0171	.544	.514	9.44191
26000	.0175	.916	.771	.14758
29000	.0181	.909	.899	.15192
41000	.0075	.985	.983	.09746
42000	.0191	.627	.554	.19822
44000	.0969	.889	.873	.06557
45000	.0175	.986	.950	6.22720
46000	.1169	.812	.778	.47179
49000	.0125	.627	.443	1.05572
51000	.1818	.827	.813	.14464
54000	.0000	.999	.999	.03376
56000	.0553	.795	.752	.35021
57000	.0454	.859	.831	.19388
61000	.0264	.951	.948	.20263
62000	.0000	.925	.925	.27271
63000	.0567	.826	.810	.17111
64000	.0150	.889	.808	.23700
65000	.1465	.744	.687	57.15566
67000	.4688	.558	.414	.43197
71000	.0139	.932	.927	.09077
72000	.0453	.964	.961	9.12977
73000	.0000	.462	.462	1.00686
74000	.0000	.692	.692	.16535
75000	.0103	.993	.992	.20720
76000	.0000	.998	.998	101.48203
91000	.1889	.883	.865	127.37901
96000	.0000	.951	.951	.17680
97000	.2143	.830	.787	.57484

CORRECTION PAGE ATTACHED

TABLE 2-7. ROTARY WING AIRCRAFT
BASELINE MFHBF PREDICTION EQUATION STATISTICS

		R^2		
WUC	k	Least Squares	Ridge	$\hat{\sigma}$
00000	.0000	.725	.670	.05701
11000	.0075	.883	.853	.42770
12000	.2743	.871	.845	.14836
13000	.0050	.941	.883	.12562
14000	.0175	.965	.953	.15824
15000	.0168	.965	.961	.05831
22000	.0175	.965	.873	5.92555
24000	.0171	.544	.514	9.44191
26000	.0175	.916	.771	.14758
29000	.0181	.909	.899	.15192
41000	.0175	.985	.977	.11314
42000	.0191	.627	.554	.19822
44000	.0969	.889	.873	.06557
45000	.0175	.986	.950	6.22720
46000	.1169	.812	.778	.47179
49000	.0125	.627	.443	1.05572
51000	.1818	.827	.813	.14464
54000	.0000	.999	.999	.03376
56000	.0553	.795	.752	.35021
57000	.0454	.859	.831	.19388
61000	.0264	.951	.948	.20263
62000	.0000	.914	.914	.29067
63000	.0567	.826	.810	.17111
64000	.0150	.889	.808	.23700
65000	.1465	.744	.687	57.15566
67000	.4688	.558	.414	.43197
71000	.0139	.932	.927	.09077
72000	.0453	.964	.961	9.12977
73000	.0000	.462	.462	1.00686
74000	.0000	.692	.692	.16535
75000	.0103	.993	.992	.20720
76000	.0000	.998	.998	101.48203
91000	.1889	.883	.865	127.37901
96000	.0000	.951	.951	.17680
97000	.2143	.830	.787	.57484

CORRECTION PAGE ATTACHED

TABLE 2-8. HISTORICAL AIRCRAFT USED FOR DEVELOPMENT OF BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT

WUC	DESCRIPTION	ASW	MARINE ASSAULT	VOD/SAR
00000	Overall Aircraft	X	X	X
11000	Airframe	X	X	X
12000	Fuselage Compartments	X	X	X
13000	Landing Gear	X	X	X
14000	Flight Controls	X	X	X
15000	Helicopter Rotor System	X	X	X
22000	Turboshaft Engines	X	X	X
24000	Aux. Power Plant Airborne		X	X
26000	Helicopter Rotary Wing	X	X	X
29000	Power Plant Installation	X	X	X
41000	Air Cond/Pres/Ice Control	X	X	X
42000	Electrical Power System	X	X	X
44000	Lighting System	X	X	X
45000	Hydraulic & Pneumatic Power	X	X	X
46000	Fuel System	X	X	X
49000	Miscellaneous Utilities	X	X	X
51000	Instruments	X	X	X
54000	Telemetry	X		
56000	Flight Reference	X	X	X

TABLE 2-8 (Cont.). HISTORICAL AIRCRAFT USED FOR DEVELOPMENT OF BASELINE MFHBF PREDICTION EQUATIONS FOR ROTARY WING AIRCRAFT

WUC	DESCRIPTION	ASW	MARINE ASSAULT	VOD/SAR
57000	Int. Guidance/Flt. Control	X	X	X
61000	HF Comm. System	X	X	X
62000	VHF Comm. System	X	X	X
63000	UHF Comm.	X	X	X
64000	Interphone System	X	X	X
65000	IFF Systems	X	X	X
67000	CNI Int. Package	X	X	
71000	Radio Navigation	X	X	X
72000	Radar Navigation	X	X	X
73000	Bombing Navigation	X		X
74000	Weapons Control	X		X
75000	Weapon Delivery	X	X	X
76000	Elec. Countermeasures	X	X	
91000	Emergency Equipment	X	X	X
96000	Personnel Equipment	X	X	X
97000	Explosive Devices	X	X	X

available, were used to develop each prediction equation. For WUC 96000, only two aircraft had three or more quarters of historical data available for computing a MFHBF value. To permit the development of a prediction equation, the MFHBF for three more aircraft were included in the MFHBF Data Base, even though the historical MFHBF value was based on fewer than three quarters of data.

3. PREDICTION OF NOTIONAL AIRCRAFT RELIABILITY

The Baseline Reliability Prediction Models have been designed to allow reliability predictions of notional aircraft MFHBF early in the aircraft's design evolution. The equations which constitute the models utilize design/performance characteristics, available during the conceptual phase, which permit aircraft reliability to become a part of the weapon system effectiveness and trade studies.

3.1 Model Application Procedure . These models are capable of providing baseline MFHBF predictions with a minimum of constraints in their application. Some of the considerations in fixed wing and rotary wing aircraft model usage, together with an example, are presented below.

Use of either Baseline Reliability Prediction Model consists of substituting notional aircraft characteristic values into the equations to predict baseline values of either the MFHBF or ln(MFHBF) for each two-digit WUC subsystem for which an equation was developed. As an example, the baseline MFHBF prediction equation for WUC 12000 (Fuselage Compartments) of fixed wing aircraft is

$$\ln(\text{MFHBF}) = 6.26009 + \sum_{i=1}^{9} b_i X_i$$

where the appropriate coefficients, b_i, and corresponding aircraft characteristics, X_i, are as given in Section 2.2. Making the appropriate substitutions, the equation becomes

$$\begin{aligned}\ln(\text{MFHBF}) = 6.26009 &+ (.00031073)(\text{Fuselage Volume})\\ &-(.00039154)(\text{Pres. Fuselage Volume})\\ &+(.00042298)(\text{Total ECS Wt.})\\ &-(.0030346)(\text{Kinetic Energy})\\ &-(.11206)(\text{No. of Internal Tanks})\\ &-(.27330)(\text{Max. Thrust to Max. T.O. Weight})\\ &-(.015924)(\text{Min. Combat Mission Time})\\ &-(.16122)(\text{Max. Speed -- Mach No.})\\ &-(1.98593)(\text{Flt. Design Wt. to Max. T.O. Weight})\end{aligned}$$

Suppose there exists a notional aircraft with the following characteristic values:

Aircraft Characteristic	Value
Fuselage Volume	950.00 cubic ft.
Pressurized Fuselage Volume	55.30 cubic ft.
Total ECS Weight	274.81 lbs.
Kinetic Energy (x 100,000)	171.028 $lbs \cdot ft^2/sec^2$
No. of Internal Tanks	7.00
Max. Thrust to Max. T.O. Weight	0.357
Min. Combat Mission Time	1.96 hrs.
Max. Speed -- Mach No.	0.91
Flt. Design Wt. to Max. T.O. Wt.	0.704

Substituting the values of the A/C characteristics into the equation, the predicted value for ln(MFHBF) is then computed to be:

$$
\begin{aligned}
\ln(\text{MFHBF}) &= 6.26009 + (.00031073)(950.00) \\
&\quad -(.00039154)(55.30) + (.00042298)(274.81) \\
&\quad -(.0030346)(171.028) - (.11206)(7.00) \\
&\quad -(.27330)(.357) - (.015924)(1.96) - (.16122)(.91) \\
&\quad -(1.98593)(.704) \\
&= 6.26009 + .29519 - .02165 + .11624 \\
&\quad -.51900 - .78442 - .09757 - .03121 - .14671 \\
&\quad -1.39809 \\
&= 3.67287
\end{aligned}
$$

Thus, the predicted value for the MFHBF of WUC 12000 (Fuselage Compartment) is

$$\text{MFHBF} = e^{3.67287}$$

or

$$\text{MFHBF} = 39.36472 \quad .$$

To apply either of the models to prediction of the MFHBF of a notional aircraft requires, as the first step, determination of the values of the aircraft design/performance parameters which occur in the model. A suggested approach is to construct a list from Table A-8 or Table A-9 of Appendix A, of the parameters for which values are needed.

The models can be readily adapted to computer application. In which case, the notional aircraft parameter values could be input to the computer from the above mentioned list. If the models are to be used manually, a suggested approach is to construct a form, using the basic format of Table 2-1, so that the values of notional aircraft design/performance parameters can be recorded on the form for each two-digit WUC subsystem of the notional aircraft. Then the necessary calculations can be made, step by step, as shown in Table 3-1, with the final step resulting in the predicted baseline MFHBF for that two-digit WUC subsystem.

It should be noted that the predicted baseline MFHBF for a given two-digit WUC subsystem is a predicted average value for a mature aircraft. That is, the predicted baseline MFHBF is an estimate of the average value for the MFHBF given the aircraft characteristics have the values specified.

In order to properly use the Baseline Reliability Prediction Models, the appropriate value for the design/performance parameters of a given baseline MFHBF prediction equation must be used. The values required are not always apparent from the variable name alone. Appendix A provides definitions of various fixed wing and rotary wing aircraft characteristics and their units and should be referred to before attempting their use in predicting the MFHBF of notional aircraft.

As mentioned in Section 2.2 and 2.3, some minor changes were made for WUC's 20000, 22000. 23000, 27000, and 29000 which affect the manner in which the associated equations are used to predict the baseline MFHBF. In both the fixed wing and rotary wing models, the equations associated with these two-digit WUC's are used to predict the baseline MFHBF for a single engine. To obtain the baseline MFHBF value for the two-digit WUC subsystem, dividing by the appropriate number of engines of the notional aircraft is required. As the prediction equations for WUC's 20000, 22000, 23000, and 27000 are expressed in terms of the MFHBF, the division by the number of engines is direct. For WUC 29000, the predicted value must first be converted from ln(MFHBF) to the MFHBF before dividing by the number of engines.

TABLE 3-1. BASELINE MFHBF PREDICTION WORKSHEET
FUSELAGE COMPARTMENTS
WUC 12000
FIXED WING AIRCRAFT

$$Z = \ln(\text{MFHBF}) = 6.26009 + \sum_{i=1}^{9} b_i X_i$$

$$\text{MFHBF} = e^Z$$

Aircraft Characteristic X_i	Value of X_i	Coefficient b_i	Product $b_i X_i$
Fuselage Volume	950.00	$.31073 \times 10^{-3}$	0.29519
Pressurized Fuselage Volume	55.30	$-.39154 \times 10^{-3}$	-0.02165
Total ECS Weight	274.81	$.42298 \times 10^{-3}$	0.11624
Kinetic Energy	171.028	$-.30346 \times 10^{-2}$	-0.51900
No. of Internal Tanks	7.00	-.11206	-0.78442
Max. Thrust to Max. T.O. Wt.	0.357	-.27330	-0.09757
Min. Combat Mission Time	1.96	$-.15924 \times 10^{-1}$	-0.03121
Max. Speed -- Mach No.	0.91	-.16122	-0.14671
Flt. Dsgn. Wt. to Max. T.O. Wt.	0.704	-1.98593	-1.39809
		Sum =	-2.58722

$$Z = 6.26009 + \text{Sum}$$
$$= 6.26009 - 2.58722$$
$$= 3.67287$$

$$\text{MFHBF} = e^Z$$
$$= e^{3.67287}$$
$$= 39.36472 \quad .$$

The Work Unit Code Manual assigns 23000 to turbojet engines and 27000 to turbofan engines. For this study, turbojet engines are associated with WUC 23000 and turbofan engines are associated with WUC 27000 though this does not necessarily correspond to the WUC Manuals. This allowed for development of prediction equations by type of engine.

3.2 Implementing Prediction Results. The models may be better used if their capabilities and limitations are understood. The models' derivation, its significant characteristics, and the few constraints should be reviewed by the prospective user before attempting their use in predicting notional aircraft baseline MFHBF.

Data base period technology and reliability practices constrain the resulting prediction equation estimates to baseline values. In the determination of the final notional aircraft reliability values, the baseline MFHBF must be adjusted to reflect potential improvements achievable through technological advances, the Navy's "New Look", duty cycle emphasis, and corrective design features to eliminate or reduce historical failure modes. By incorporating these improvement factors into the baseline MFHBF predicted values, the "then-year" prediction of the MFHBF for two-digit WUC subsystems of fixed wing and rotary wing notional aircraft is obtained.

The objective of the Baseline Reliability Prediction Models is to predict the overall MFHBF of fixed wing and rotary wing notional aircraft. Having derived the then-year MFHBF for each two-digit WUC of the aircraft, the aircraft MFHBF is then calculated by summing the reciprocals of the then-year two-digit WUC MFHBF values and then taking the reciprocal of the sum. By predicting the MFHBF at a two-digit WUC level, the prediction for the notional aircraft MFHBF should be more responsive to the overall configuration and less sensitive to specific design/performance features of the aircraft.

The goal of the regression analysis performed in the study was to derive the "best" linear functional relationship between the MFHBF or ln(MFHBF) and the aircraft design/performance parameters for each two-digit WUC subsystem considered. The goal of the regression analysis was not to determine which aircraft parameters were the cause of the failures at a two-digit WUC level. The appearance of a parameter in a baseline MFHBF prediction equation cannot be interpreted as an indication of a "cause and effect" relationship. Similarly, the sign of the coefficients for the variables in a baseline MFHBF prediction equation cannot be interpreted as the direction of the linear association or correlation between the variable and the MFHBF for the subsystem. The linear association between the predictor variables themselves may have influenced the signs of the coefficients.

Various differences between existing and notional or conceptual aircraft designs have affected the development of the Baseline Reliability Prediction Models and might modify its usage. For example, the current WUC structure may not be representative of future aircraft equipment and functional partitioning. Some design/performance characteristics of existing aircraft establish data boundaries which may not be consistent with those of notional aircraft. The values for notional aircraft characteristics, such as the Maximum Rate of Climb at Sea Level, Turbine Inlet Temperature, Total Aircraft Thrust and Thrust to Weight Parameters, may lie outside the range of existing aircraft data and thus require extrapolation. For some notional design/performance parameters an equivalent parameter is not found in existing aircraft; therefore, the characteristics cannot be considered in the model. Other characteristics require a modified definition to use the equations for prediction of notional aircraft reliability. Any aircraft characteristics requiring modified definitions and/or explanations for notional aircraft are noted in Table A-6 of Appendix A.

Part II

Model Development

4. DATA BASE DEVELOPMENT

Two types of data were required in the performance of this study. The first, reliability data, was obtained as Mean Flight Hours Between Failure (MFHBF) values for historical Navy aircraft from the Navy's fleetwide data system. The second, that of aircraft design/performance parameters, was obtained from a number of sources discussed in Section 4.3. These two types of data comprise the MFHBF Data Bases and Design/Performance Data Bases respectively. These data bases were used to develop two reliability prediction models, one for fixed wing aircraft and the other for rotary wing aircraft, at the two-digit Work Unit Code (WUC) level. Each model required a separate MFHBF and Design/Performance Data Base.

MFHBF data at the two-digit WUC subsystem level and aircraft design/performance parameters were obtained on each of 43 Navy aircraft. Of these aircraft thirty-two were fixed wing and eleven were rotary wing. The data sources, data collection, adjustments, and analysis are discussed in the following sections.

4.1 Data Background. The Fleet Weapon System Reliability and Maintainability Statistical Summary Tabulation Report, MSO 4790.A2142.01 is based on the Navy's Maintenance and Material Management (3M) system. This report presents reliability and maintainability summaries by Work Unit Code (WUC) for all Navy aircraft. The MSO Reports prior to July 1976 are based on semi-annual reporting periods, and reports after this date have quarterly reporting periods. In order to obtain data from reporting periods of equal duration, only reports from July 1976 forward were used in this study. The last report that could be included was the quarter ending with June 1979. Therefore, the MFHBF data was collected over the time period of July 1976 through June 1979 (twelve quarters).

From the fleet aircraft presented in the MSO reports, the thirty-two fixed wing and eleven rotary wing aircraft shown in Table 4-1 were selected for use in this study. The criteria used in selecting the aircraft for the study

TABLE 4-1. NAVY AIRCRAFT USED IN THE DEVELOPMENT OF THE RELIABILITY PREDICTION MODELS

FIXED WING AIRCRAFT (32)

- o Fighter
  - F-4J, N
  - F-14A
- o Attack
  - A-4E, F, M
  - A-6A, E
  - A-7A, B, C, E
  - AV-8A
- o Reconnaissance
  - RF-4B
  - RF-8G
  - RA-5C
- o Electronic Warfare
  - EA-3B
  - EA-6A, B
- o Airborne Early Warning
  - E-1B
  - E-2B, C
- o Anti-Submarine Warfare
  - S-3A
- o Patrol Anti-Submarine Warfare
  - P-3A, B, C
- o Carrier On Board Delivery Transport
  - C-1A
  - C-2A
- o Flight Refueling Tanker
  - KA-3B
  - KA-6D
  - KC-130F, R

ROTARY WING AIRCRAFT (11)

- o Anti-Submarine Warfare
  - SH-2F
  - SH-3A, D, G, H
- o Marine Assault
  - CH-46D, F
  - CH-53A, D
- o Vertical on Board Delivery/ Search and Rescue
  - HH-3A
  - HH-46A

required that:

- o historical aircraft be as representative as possible of notional Navy aircraft including those in the Sea Based Air Master Study (SBAMS).
- o MFHBF data for the historical aircraft be available.
- o design/performance data for the historical aircraft be available.

It was necessary to exclude certain aircraft from the study due to a shortage of data. The fixed wing aircraft, A-4L, F-4S, EA-4F, and EC-130Q had to be excluded since most of the design/performance values were not available. For the rotary wing aircraft the SH-2D, CH-46A, HH-1K, and CH-53E were excluded because MFHBF data was not available from the MSO Reports for the twelve quarters covered by the study.

A compromise was required in order to include the F-4N and E-2B in the fixed wing aircraft data bases. Design/performance parameters were available for the F-4B but the aircraft was phased out of fleet operations by the second quarter of 1977, having been modified to the F-4N configuration. The time period from July 1976 through the second quarter of 1977 contained insufficient quarterly data for computing a stable MFHBF for the F-4B. The F-4B, therefore, could not be included in the data bases. On the other hand, F-4N MFHBF data was available from the MSO Reports, but design/performance parameters were not available. Examination of the modifications made to the F-4B to produce the F-4N, revealed no changes that would significantly affect the value of any design/performance parameters as used in this study. Therefore, it was decided to use the F-4B design/performance parameters with the F-4N MFHBF values. Similarly, the updating of the E-2A to the E-2B resulted in the use of E-2B MFHBF values with E-2A design/performance parameters.

Certain two-digit WUC subsystems, such as WUC 53000 (Guidance Systems - Drones) and WUC 58000 (In-Flight Test Equipment) were not considered. Since WUC 53000 applies to drone aircraft such as the QF-4B, it was not considered applicable to this study. While the E-2B, E-2C, F-14A, and P-3C have failure data reported in the MSO Reports for WUC 58000 for some quarters, the quarterly MFHBF values calculated for these aircraft vary widely. Due to the limited quantity of data and the wide variance in the calculated quarterly

MFHBF, it was judged that a meaningful prediction equation could not be derived. Other two-digit WUC subsystems were not included because sufficient failure data was not available from the MSO Reports during the time period used in the study.

4.2 MFHBF Data Bases. The MFHBF Data Bases were developed at the two-digit WUC level using historical aircraft data for fixed and rotary wing aircraft. The quarterly MSO Reports were used as the source of reliability information for the MFHBF Data Bases.

4.2.1 Collection of Data. Reliability data for the fixed and rotary wing aircraft were collected from the quarterly MSO Reports covering the time period from July 1976 through June 1979 (twelve quarters). For each quarter, the Navy-wide totals for the number of failures at the two-digit WUC subsystem level and the corresponding aircraft flight hours were obtained for forty-three aircraft.

Data was collected for 38 two-digit WUC subsystems for fixed wing aircraft and 34 WUC subsystems for rotary wing aircraft in accordance with the respective WUC Manuals. Failure data was also collected at the overall aircraft level for the 43 aircraft. WUC 00000 was created to represent the MFHBF values and the prediction equation developed for the overall aircraft. An additional WUC was created for the fixed wing aircraft and was denoted as WUC 20000. This WUC subsystem contains the MFHBF values for both WUC 23000 (Turbojet Engines) and WUC 27000 (Turbofan Engines). A list of the 40 fixed wing and 35 rotary wing WUC subsystems for which prediction equations were developed along with the number of MFHBF values available for prediction equation development is presented in Tables 4-2 and 4-3. Notice that for certain WUC subsystems, MFHBF data was not available for all thirty-two fixed wing or eleven rotary wing aircraft. Because of the differences in historical aircraft not all WUC subsystems applied to all aircraft. For example, only seven fixed wing aircraft have Auxiliary Power Plants (WUC 24000). In addition, some MFHBF values were deleted from certain WUC subsystems in the MFHBF Data Base due to limited or extreme data. The criteria for deletion of the MFHBF values is given in Section 4.2.2.2.

TABLE 4-2. RELIABILITY PREDICTION MODEL WUC'S AND WUC DATA AVAILABILITY (FIXED WING AIRCRAFT)

	TWO-DIGIT WUC	DESCRIPTION	NO. OF A/C WITH MFHBF VALUES AVAILABLE FOR PREDICTION EQUATION DEVELOPMENT
	00000 (1)	Total Aircraft	32
Aircraft Basic	11000	Airframe	32
	12000	Fuselage Compartments	32
	13000	Landing Gear	32
	14000	Flight Controls	32
	20000 (1)	Turbojet and Turbofan Engine	22
Power Plant	22000	Turboshaft Engines	8
	23000	Turbojet Engines	15
	24000	Aux. Pwr. Plant Airborne	7
	27000	Turbofan Engines	7
	29000	Power Plant Instl.	32
Utilities	41000	Air Cond/Pres/Ice Contr.	32
	42000	Electrical Power Sys.	32
	44000	Lighting System	32
	45000	Hydraulic & Pneumatic Pwr	32
	46000	Fuel System	32
	47000	Oxygen Systems	30
	49000	Misc. Utilities	31
Instrumentation	51000	Instruments	32
	56000	Flight Reference	32
	57000	Int. Guidance/Flt.Contr.	25
Communications	61000	HF Communications System	14
	62000	VHF Communications Sys.	14
	63000	UHF Communications	31
	64000	Interphone System	27
	65000	IFF Systems	30
	66000	Emergency Radio	20
	67000	CNI Integrated Package	23
	69000	Misc. Comm. Equipment	9
Weapon Navigation/ Control	71000	Radio Navigation	30
	72000	Radar Navigation	32
	73000	Bombing Navigation	27
	74000	Weapons Control	20
	75000	Weapons Delivery	21
	76000	Elec. Countermeasures	25
	77000	Photographic/Reconnaissance	13
Misc. Equipments/ Systems	91000	Emergency Equipment	32
	93000	Deceleration Equipment	6
	96000	Personnel Equipment	20
	97000	Explosive Devices	22

(1) Non-standard WUC

TABLE 4-3. RELIABILITY PREDICTION MODEL WUC'S AND WUC DATA AVAILABILITY (ROTARY WING AIRCRAFT)

	TWO-DIGIT WUC	DESCRIPTION	NO. OF A/C WITH MFHBF VALUES AVAILABLE FOR PREDICTION EQUATION DEVELOPMENT
	00000 (1)	Total Aircraft	11
Aircraft Basic	11000	Airframe	11
	12000	Fuselage Compartments	11
	13000	Landing Gear	11
	14000	Flight Controls	11
	15000	Helicopter Rotor System	11
Power Plant	22000	Turboshaft Engines	11
	24000	Aux. Pwr. Plant Airborne	5
	26000	Helicopter Rotary Wing	11
	29000	Power Plant Instl.	11
Utilities	41000	Air Cond/Pres/Ice Contr.	9
	42000	Electrical Power Sys.	11
	44000	Lighting System	11
	45000	Hydraulic & Pneumatic Pwr	11
	46000	Fuel System	11
	49000	Miscellaneous Utilities	11
Instrumentation	51000	Instruments	11
	54000	Telemetry	4
	56000	Flight Reference	11
	57000	Int. Guid/Flt. Control	11
Communications	61000	HF Communications Sys.	9
	62000	VHF Communications Sys.	6
	63000	UHF Communications Sys.	11
	64000	Interphone System	11
	65000	IFF Systems	11
	67000	CNI Integrated Package	9
Weapon Navigation/ Control	71000	Radio Navigation	11
	72000	Radar Navigation	11
	73000	Bombing Navigation	6
	74000	Weapons Control	6
	75000	Weapons Delivery	8
	76000	Elect. Countermeasures	4
Misc. Equipments/ Systems	91000	Emergency Equipment	11
	96000	Personnel Equipment	5
	97000	Explosive Devices	9

(1) Non-standard WUC

In accordance with the WUC Manuals, the engine failures for the F-14A, A-7A, B, C, and E aircraft were reported against WUC 23000 (Turbojet Engines) in the MSO Reports. However, these five aircraft have a turbofan engine. Since the engine prediction equations were to be developed by type of engine, the historical MFHBF data for these five aircraft were moved from WUC 23000 to WUC 27000 (Turbofan Engines).

The twelve quarters of data were split into two groups. The eight quarters of data from July 1976 through June 1978 to be used for model development, and the four quarters from July 1978 through June 1979 were to be used to verify the stability of the first eight quarters. The MFHBF values for the two-digit WUC subsystems of the 43 aircraft were calculated for each of the twelve quarters and for both the eight and four quarter time periods using the formula:

$$\text{MFHBF} = \frac{\text{total flight hours}}{\text{total number of failures}} \qquad (4.1)$$

It should be noted that the MFHBF values in the MFHBF Data Base for WUC 20000 (Turbojet/Turbofan Engines), WUC 22000 (Turboshaft Engines), WUC 23000 (Turbojet Engines), WUC 27000 (Turbofan Engines), and WUC 29000 (Power Plant Installation) have been adjusted to a per engine basis where an aircraft has more than one engine.

An effort was made to standardize the WUC's relative to the Standardized WUC Manual for the fixed wing aircraft used in this study. This effort involved the A-4M, A-6E, A-7E, AV-8A, and F-14A. The standardization of these five aircraft proved to be a larger undertaking in terms of time and manpower than originally believed. This led to an agreement with NAVAIR that the standardization of the WUC's was beyond the scope of the funded effort. Therefore, the MFHBF values in the data bases were not standardized for either the fixed or rotary wing aircraft.

4.2.2 Analysis of MFHBF Data. In order to ensure that the reliability information for the data base was, in fact, representative of the long term

MFHBF, some form of verification was required. Verification of the data's stability was obtained through a comparison of the MFHBF values for the eight quarters representing the candidate MFHBF data bases and the subsequent four quarters established for use in verification. The data was also examined for trends and variability that might affect the stability of the data.

Through analysis of the MFHBF data, it was determined that no consistent trends or unusual variability existed over time at the two-digit WUC level. Therefore, the MFHBF values calculated for the time period consisting of the eight quarters from July 1976 through June 1978, were considered sufficiently stable to be used to develop the historical MFHBF Data Bases for the fixed and rotary wing aircraft. Tables A-1 and A-2 of Appendix A, present the minimum and maximum values of the MFHBF Data Bases and the verification data by two-digit WUC subsystems for the fixed and rotary wing aircraft.

4.2.2.1 Trends, Variability and Stability. The MFHBF data was analyzed for consistent trends and variability. These analyses were performed among different aircraft for a given two-digit WUC, as well as between different two-digit WUC subsystems of a given aircraft for both fixed and rotary wing aircraft. When the quarterly MFHBF values of all fixed wing aircraft for a given WUC were plotted against the twelve data quarters a wide variety of patterns resulted. While some individual patterns showed definite trends, there was no consistent trend present for all aircraft. As an example, the quarterly MFHBF data of the A-6E, A-7E, and F-14A fixed wing aircraft for WUC 13000 (Landing Gear) is presented in Table 4-4, and is shown graphically in Figure 4-1. Also, a variety of patterns were obtained when the MFHBF values of all WUC subsystems for a given fixed wing aircraft were plotted against the twelve quarters of data. Again, some individual patterns showed definite trends, but no consistent trends present in all WUC subsystems. An example of this is presented for the A-6E in Table 4-5 and plotted in Figure 4-2. The same type of analysis was performed on the rotary wing aircraft with similar results. Examples of these results are shown in Tables 4-6, and 4-7, and Figures 4-3 and 4-4.

The variability in the quarterly MFHBF data was also examined. Again, the data was examined by comparing different WUC subsystems within the same

TABLE 4-4. LANDING GEAR (WUC 13000) MFHBF VS REPORTING PERIOD FOR THE A-6E, A-7E, AND F-14A

Reporting Period	MFHBF A-6E	MFHBF A-7E	MFHBF F-14A
Data Base Period			
Jul - Sep 1976	15.78	11.65	12.80
Oct - Dec 1976	14.36	11.16	12.39
Jan - Mar 1977	14.51	10.72	14.18
Apr - Jun 1977	15.05	10.31	12.11
Jul - Sep 1977	14.90	10.68	11.28
Oct - Dec 1977	14.79	10.63	11.01
Jan - Mar 1978	15.35	10.81	9.76
Apr - Jun 1978	18.74	11.64	11.89
Jul 1976 - Jun 1978 (8 Quarters)	15.44	10.90	11.74
Data Base Verification Period			
Jul - Sep 1978	16.72	10.94	12.13
Oct - Dec 1978	16.50	11.08	13.91
Jan - Mar 1979	15.83	11.18	11.96
Apr - Jun 1979	15.94	11.24	12.49
Jul 1978 - Jun 1979 (4 Quarters)	16.24	11.11	12.59

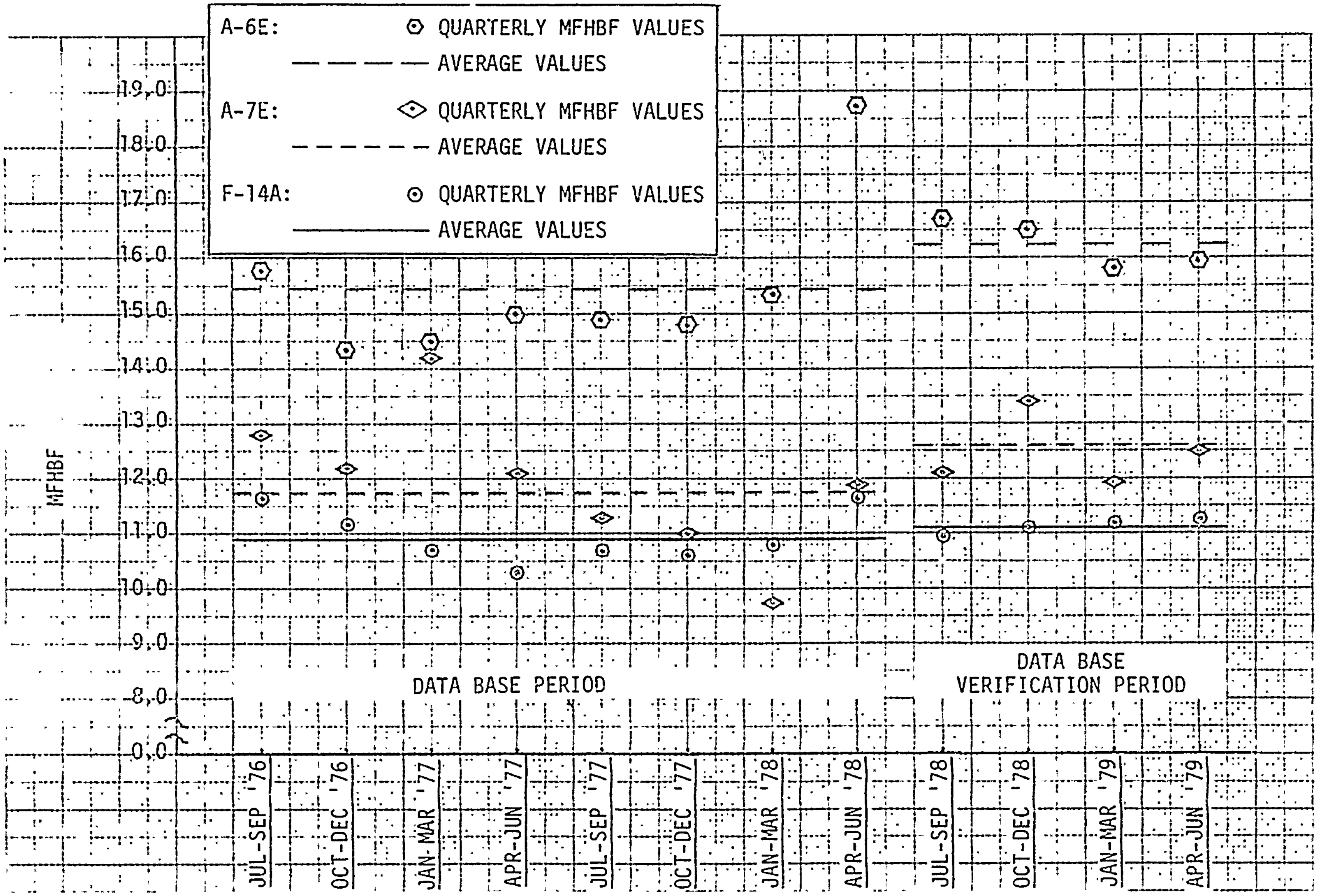

Figure 4-1. Landing Gear (WUC 13000) MFHBF vs. Reporting Period for Selected Fixed Wing Aircraft

TABLE 4-5. A-6E MFHBF VS REPORTING PERIOD FOR WUC'S 11000, 13000, AND 73000

Reporting Period	MFHBF WUC 11000	MFHBF WUC 13000	MFHBF WUC 73000
Data Base Period			
Jul-Sep 1976	7.47	15.78	9.75
Oct-Dec 1976	6.87	14.36	9.73
Jan-Mar 1977	5.81	14.51	9.92
Apr-Jun 1977	5.88	15.05	10.00
Jul-Sep 1977	5.50	14.90	10.25
Oct-Dec 1977	5.02	14.79	10.29
Jan-Mar 1978	5.96	15.35	10.95
Apr-Jun 1978	6.09	18.74	10.64
Jul 1976 - Jun 1978 (8 Quarters)	5.98	15.44	10.23
Data Base Verification Period			
Jul-Sep 1978	5.76	16.72	9.99
Oct-Dec 1978	6.35	16.50	9.99
Jan-Mar 1979	5.28	15.83	10.64
Apr-Jun 1979	5.38	15.94	8.05
Jul 1978 - Jun 1979 (4 Quarters)	5.66	16.24	9.63

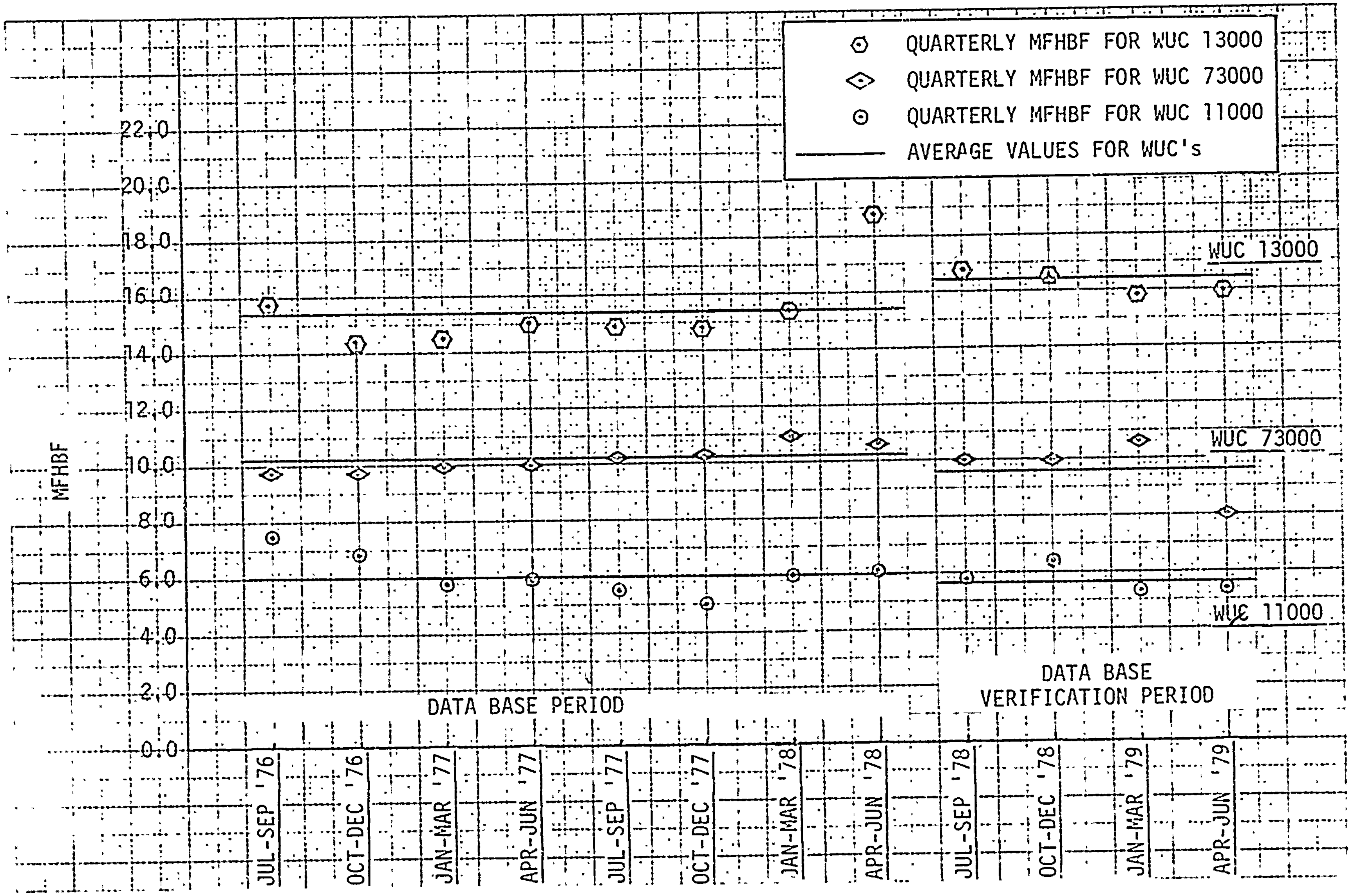

Figure 4-2. A-6E MFHBF vs. Reporting Period for Selected WUC's

TABLE 4-6. HELICOPTER ROTOR SYSTEM (WUC 15000) MFHBF VS REPORTING PERIOD FOR THE CH-46F, SH-2F, AND SH-3H

Reporting Period	MFHBF CH-46F	MFHBF SH-2F	MFHBF SH-3H
Data Base Period			
Jul - Sep 1976	7.40	9.11	9.85
Oct - Dec 1976	7.88	9.08	12.51
Jan - Mar 1977	6.68	9.53	14.76
Apr - Jun 1977	7.29	8.97	12.90
Jul - Sep 1977	7.18	7.91	10.08
Oct - Dec 1977	6.92	6.06	10.80
Jan - Mar 1978	5.76	4.99	11.61
Apr - Jun 1978	5.84	7.25	11.08
Jul 1976 - Jun 1978 (8 Quarters)	6.76	7.65	11.47
Data Base Verification Period			
Jul - Sep 1978	7.06	7.23	9.31
Oct - Dec 1978	5.80	6.68	11.86
Jan - Mar 1979	7.49	6.06	12.51
Apr - Jun 1979	7.32	5.40	9.42
Jul 1978 - Jun 1979 (4 Quarters)	6.80	6.25	10.72

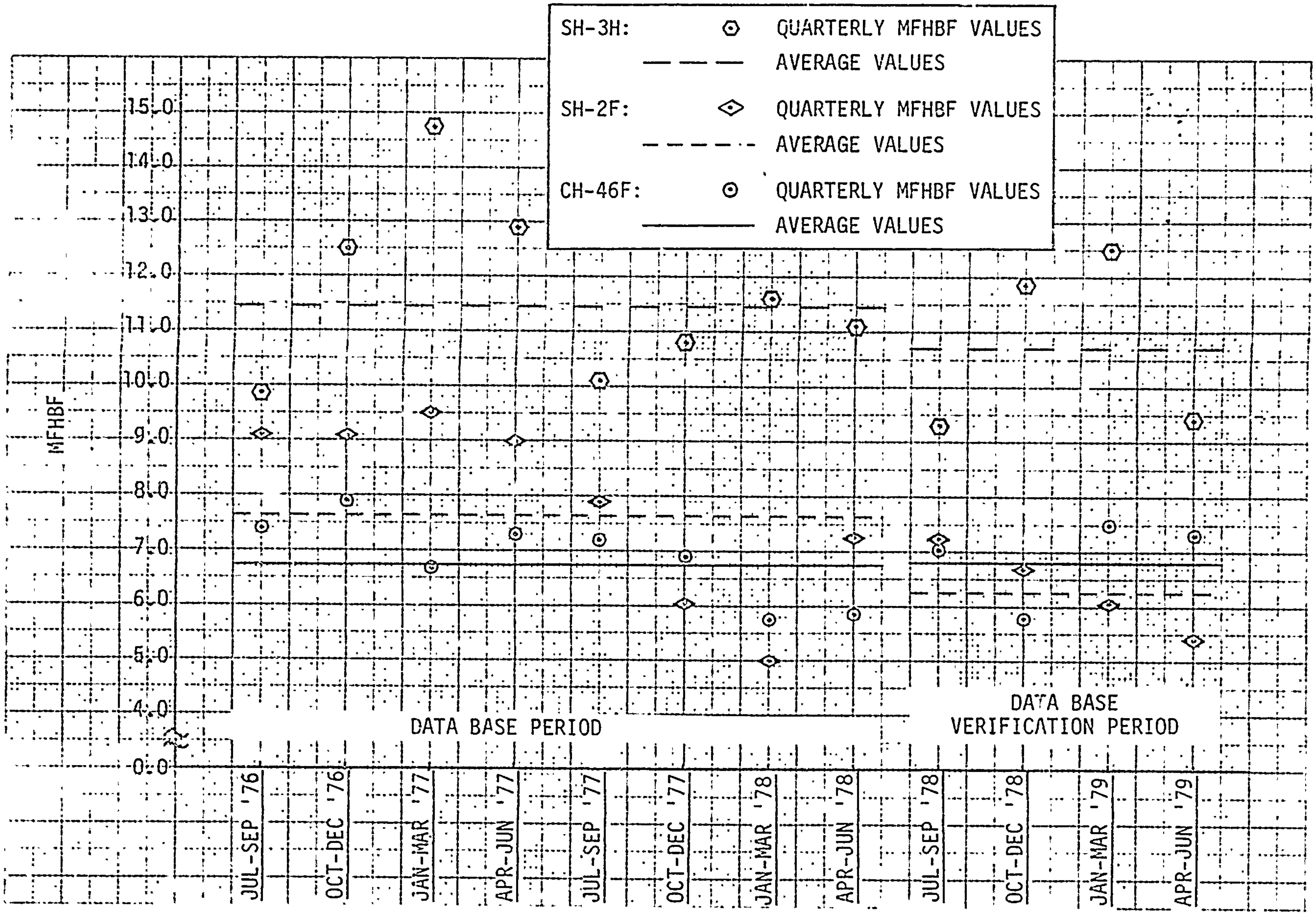

Figure 4-3. Helicopter Rotor System (WUC 15000) MFHBF vs. Peporting Period for Selected Rotary Wing Aircraft

TABLE 4-7. SH-3H MFHBF VS REPORTING PERIOD FOR WUC'S 11000, 15000, AND 73000

Reporting Period	MFHBF WUC 11000	MFHBF WUC 15000	MFHBF WUC 73000
Data Base Period			
Jul-Sep 1976	5.69	9.85	7.83
Oct-Dec 1976	5.09	12.51	8.59
Jan-Mar 1977	6.60	14.76	10.91
Apr-Jun 1977	6.77	12.90	10.62
Jul-Sep 1977	5.73	10.08	7.59
Oct-Dec 1977	4.59	10.80	7.34
Jan-Mar 1978	4.22	11.61	7.26
Apr-Jun 1978	3.97	11.08	7.71
Jul 1976 - Jun 1978 (8 Quarters)	4.97	11.47	8.14
Data Base Verification Period			
Jul-Sep 1978	3.70	9.31	7.12
Oct-Dec 1978	4.48	11.86	9.33
Jan-Mar 1979	4.65	12.51	8.42
Apr-Jun 1979	4.42	9.42	7.84
Jul 1978 - Jun 1979 (4 Quarters)	4.31	10.72	8.15

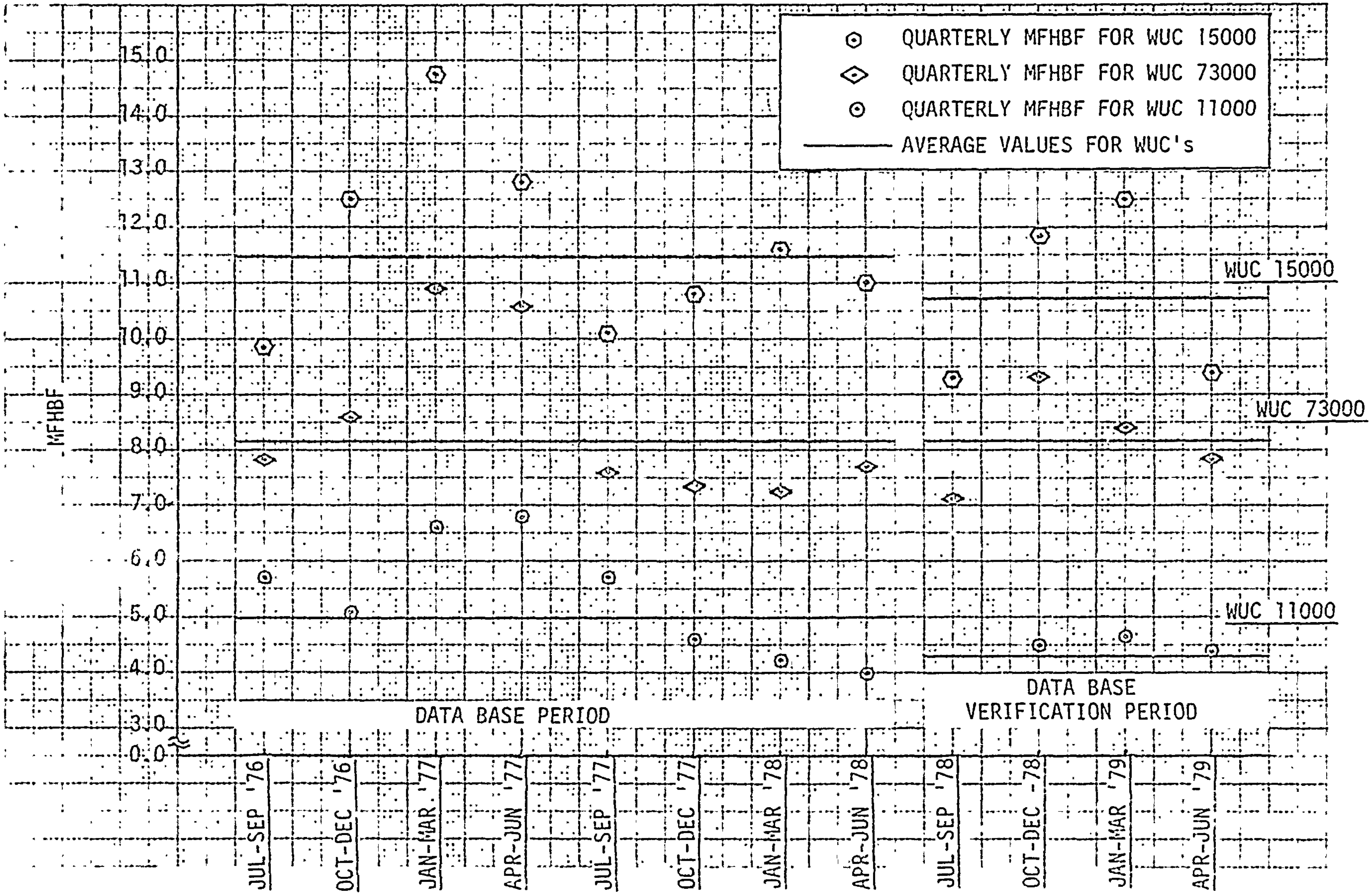

Figure 4-4. SH-3H MFHBF vs. Reporting Period for Selected WUC's

aircraft as well as different aircraft for the same WUC. The major area of concern was for those WUC subsystems which had only a few failures reported each quarter for a given aircraft that had approximately the same number of flight hours for each quarter. For these WUC subsystems a small change in the reported number of failures for a quarter could have made a significant change in successive quarterly MFHBF values. Having been made aware of this potential problem, the omission of these aircraft on a selective WUC basis was in order should these individual aircraft have prohibited the development of a good baseline MFHBF prediction equation. For example, the MFHBF of WUC 97000 (Explosive Devices) for the A-6E varied from 20,817 (1 failure in 20,817 hours) to 2,132 (7 failures in 14,924 hours). For some aircraft, variability occured due to the aircraft being phased into service or out of service. For an aircraft phasing into service, both the flight hours and the number of failures tended to increase with time and the variability tended to decrease. With an aircraft phasing out of service, the reverse tended to occur.

The long term stability of the MFHBF data was examined by comparing the average MFHBF value of the candidate data base (eight quarters) with the average MFHBF value of the verification data (four quarters). As before, multiple aircraft were compared for a given WUC, and multiple WUC subsystems were compared for a given aircraft. In some cases the average MFHBF value of the verification data was higher than the candidate data base and lower in other cases. Again, the data showed no consistent trends, and none of the differences between the average MFHBF values of the two time periods were considered significant. Examples of this analysis are shown in Tables 4-4 through 4-7 and Figures 4-1 through 4-4.

4.2.2.2 Outliers. The MFHBF data was also examined for the presence of outliers, i.e., extreme MFHBF values which might exist for a given WUC. The procedure used to check for potential outlier values was to compare the MFHBF values within a given two-digit WUC subsystem. Comparisons were made for each two-digit WUC subsystem considered in the study.

For those WUC subsystems where potential outliers were detected, bivariate plots of the MFHBF values, for the given WUC, versus various design/performance parameters were examined. If the points associated with the extreme MFHBF values were consistently incompatible with the other values on the graphs, a cause for the deletion of the extreme MFHBF value, was sought. The fact that a MFHBF value was considerably larger or smaller than the other MFHBF values for a given WUC was not sufficient reason for labeling the value an outlier. The term "outlier" applies to the data values which are found to lie outside the general pattern formed by the other data values graphed.

In order to delete an outlying MFHBF value from the data base for a given WUC, a valid reason had to be established. The reason most frequently found to apply was the extreme shortage of quarterly data. Those MFHBF values computed from only one or two quarters of data and determined to be outliers, were deleted from the MFHBF Data Base. In all, a total of 17 MFHBF values for fixed wing aircraft and 12 MFHBF values for rotary wing aircraft were deleted.

Those outlying MFHBF values that were based on a relatively small number of flight hours and/or small number of failures, were kept in the MFHBF Data Base until their effect on the development of the prediction equation for the WUC could be determined. If the effect was found to be adverse, i.e., if this MFHBF value was hindering a proper fit to the data, the value was omitted from the development of the specific WUC prediction equation. Otherwise, it remained in the data base.

4.3 Design/Performance Data Bases. The completed data bases consisted of 101 design/performance parameters for each of the thirty-two fixed wing aircraft and 89 parameters for each of the eleven rotary wing aircraft. These parameters, compiled from a number of sources, served as the independent variable data base for the regression analysis used in developing the reliability prediction equations. These parameters were chosen with the assistance of design and systems engineers and NAVAIR personnel.

4.3.1 Data Collection. The major data sources used in developing the Design/Performance Data Base were the following:

- Standard Aircraft Characteristics Charts (MIL-C-5011A)
- Group Weight Statements (MIL-STD-1374)
- Jane's All the World's Aircraft
- Aircraft and Engine Companies

- o NATOPS Flight Manuals
- o Aviation Week and Space Technology, Specifications, pages 88-142, dtd March 12, 1979

Many of the physical characteristics and performance parameters in the data bases appear in more than one of the above sources; thus, an organized procedure for collection of the data was required. The Standard Aircraft Characteristics (SAC) Charts and the Group Weight Statements were used as the primary sources. See Tables A-3 and A-4 of Appendix A for examples of these primary data sources. The remaining sources were used to obtain information not available from these two primary sources. The engine companies, in particular, provided information on several engine parameters which were not readily available. In a few instances, NAVAIR personnel provided specific information. In some cases, where no data was available, parameter values were estimated using related information available on similar aircraft. A list of the estimated parameters are provided in Table A-5 of Appendix A.

The aircraft characteristics included in the Design/Performance Data Bases were divided into four groups as follows:

- o physical characteristics including dimensions, volumes, and weights,
- o performance parameters including speed, range, altitude, and rate of climb,
- o engine characteristics including thrust, size, weight, and fuel consumption,
- o categorical/derived parameters, including indicator variables, squared characteristic values, ratios of physical characteristics, and interaction terms.

These groups are presented in Tables 4-8 through 4-11 for the fixed wing aircraft, and Tables 4-12 through 4-15 for the rotary wing aircraft. These represent the candidate predictor parameters for the thirty-two fixed wing and eleven rotary wing aircraft. Most of the characteristics are discussed in MIL-C-5011A, MIL-STD-1374A, and SD-24K (Vols. I and II) (see References 4, 5, 6, and 7). Parameters requiring additional explanation and/or with modified

TABLE 4-8. PHYSICAL CHARACTERISTICS - FIXED WING AIRCRAFT

Crew Size
No. of Moveable Flt Control Surfaces
No. of Fixed Inlets
No. of Variable Inlets
No. of Vertical Tails
Wing Sweep at 1/4 Chord
No. of External Armament Stores
Landing Sink Speed (Limit)
Tail Span
Wing Span -- Unfolded
Wing Span -- Folded
No. of Wing Plus Tails Folds
Max. Aircraft Length
Max. Aircraft Height
Mean Aerodynamic Chord (MAC)
Wheelbase
Main Gear Tread
Fuselage Wetted Area
Wing Wetted Area
Wing Area
Total Wetted Area
Fuselage Volume
Aspect Ratio
No. of External Store Stations

Flight Control Surface Area
Gun Weight
No. of Guns
Pressurized Fuselage Volume
Avionics Weight Installed
Avionics Weight Uninstalled
Auxiliary Power Unit
Total Generator Electrical Power
Total ECS Weight
Fuel Capacity Internal Wing
Fuel Capacity Internal Fuselage
Fuel Capacity External Tanks
Fuel Capacity Max. Internal
Total Fuel Capacity
No. of External Tanks
No. of Internal Tanks
Empty Weight
Flight Design Weight
Design Load Factor - Subsonic
Max. Take-off Weight (Cat)
Max. Ldg. Weight (Arrested)
Max. Payload
Max. Wing Loading

TABLE 4-9. PERFORMANCE PARAMETERS - FIXED WING AIRCRAFT

Max. Rate of Climb at Sea Level	Min. Combat Mission Time
Min. Time: Sea Level to 30K Feet	Max. Combat Mission Time
Max. Service Ceiling	Max. Speed -- Mach No.
Min. Time: Sea Level to 20K Feet	Min. Stall Speed - Approach Pwr
Max. Combat Radius	Min. Ldg. Distance
	Max. Speed at Sea Level

TABLE 4-10. ENGINE CHARACTERISTICS - FIXED WING AIRCRAFT

No. of Engines	Fuel to Air Ratio
Max. Thrust per Engine	Max. Thrust or SHP per Engine
Total Aircraft Thrust -- Military	Engine Weight Installed per Engine
Max. Engine Diameter	No. of Fan Plus Compressor Stages
Max. Engine Length	No. of Turbine Stages
No. of Engine Parts	Max. Compression Ratio
Specific Thrust or Specific SHP	Specific Fuel Consumption
Max. Airflow	Turbine Inlet Temperature
Max. Pressure Ratio	Bypass Ratio
	Engine Wt. Uninstalled per Engine

TABLE 4-11. CATEGORICAL/DERIVED PARAMETERS - FIXED WING AIRCRAFT

Recce. Indicator

Ew Indicator

Date 1st Flt. -- Prototype

Date 1st Flt. -- Series

Aircraft Carrier or Land Based

Afterburner Indicator

Type A or B

(Max. Rate of Climb) x (Type A or B)

(Max. Speed -- Mach No.) x (Type A or B)

(Max. Speed at S.L.) x (Type A or B)

(Min. Combat Mission Time) x (Type A or B)

(Avionics Wt. Installed) x (Type A or B)

(Max. Wing Loading) x (Type A or B)

(Min. Time: Sea Level to 30K Feet)^2

(Min. Time: Sea Level to 20K Feet)^2

Max. Thrust or SHP to Engine Weight Uninst.

Flight Design Weight to Max. T.O. Weight

Mil. Thrust to Design Weight

Max. Thrust to Engine Weight Installed

Max. Thrust to Max. T.O. Weight

Max. Thrust to Max. Landing Weight

(Total Fuel Capacity)^2

(Fuel Capacity External Tanks)^2

Kinetic Energy

TABLE 4-12. PHYSICAL CHARACTERISTICS - ROTARY WING AIRCRAFT

Empty Weight
Max. T.O. or Landing Weight
Design Load Factor
Crew Size
No. of Troops
No. of Main Rotor Blades
No. of Tail Rotor Blades
Main Rotor Radius
Tail Rotor Radius
Fuselage Length -- Folded
Fuselage Depth -- Folded
Fuselage Width -- Folded
Aircraft Length -- Operating
Aircraft Span -- Operating
Aircraft Width -- Operating
Wheelbase
Main Gear Tread
Main Rotor Blade Chord
Tail Rotor Blade Chord
No. External Launch Points
Max. No. of External Armament Stores
No. of External Torpedo Store Stations
No. of Internal Sonobuoy Stores
Rotor Weight
Blade Loading

Total Rotor Disc Area (Sweep)
-- Main + Tail
Total Blade Area -- Main + Tail
Main Rotor Disc Area (Sweep)
Tail Rotor Disc Area (Sweep)
Main Rotor Blade Area
Per Blade
Tail Rotor Blade Area
Per Blade
Main Rotor Blade Area (Total)
Tail Rotor Blade Area (Total)
Avionics Weight Installed
Avionics Weight Uninstalled
Total ECS Weight
Air Conditioning Weight
Anti-Icing Weight
No. of Aircraft Generators
Generator Electrical Power per Gen
Total Generator Electrical Power
Fuel Capacity Internal
Fuel Capacity Auxiliary
Total Fuel Capacity
No. of Internal Tanks
No. of Auxiliary Tanks
Max. Disc Loading

TABLE 4-13. PERFORMANCE PARAMETERS - ROTARY WING AIRCRAFT

Vertical Rate of Climb at Sea Level -- Military Power
Absolute Hovering Ceiling -- Military Power
Max. Rate of Climb -- Normal Power
Max. Service Ceiling
Max. Speed at Sea Level
Max. Combat Radius
Max. Combat Range
Max. Speed at Altitude
Associated Altitude for Max. Speed
Average Cruising Speed -- Primary Mission
Cruising Altitude -- Primary Mission

TABLE 4-14. ENGINE CHARACTERISTICS - ROTARY WING AIRCRAFT

No. of Engines

Total Aircraft SHP -- Mil. or Int. Power

Total Aircraft SHP -- Normal Power

Military or Int. SHP per Engine

Normal SHP Per Engine

Max. Engine Diameter

Max. Engine Length

Engine Weight Installed per Engine

No. of Fan Plus Compressor Stages

No. of Turbine Stages

Max. Compresion Ratio

Specific Fuel Consumption -- Mil. or Int. Power

Specific Fuel Consumption -- Normal Power

Turbine Inlet Temperature

No. of Engine Parts

Main Rotor Gear Ratio

Main Rotor Tip Speed at Design Limit

Main Rotor Transmission Limits -- SHP

Main Rotor Transmission Limits -- RPM

Power Transmission Weight -- w/o Rotor

Engine RPM -- Mil. or Int. Power

TABLE 4-15. CATEGORICAL/DERIVED PARAMETERS - ROTARY WING AIRCRAFT

Tail Pylon Fold

Date of 1st Flt. -- Series

Date of 1st Flt. -- Prototype

Date of 1st Flt. -- Service

Total Aircraft SHP -- Normal Power to Max. Take-Off Wt.

Mil. SHP per Eng. to Eng. Wt. Instl. per Eng.

Total Aircraft SHP -- Mil. or Int. Power to Max. Take-off Wt.

No. of Mission Variants

Auxiliary Power Unit

MA Indicator

definitions are listed under General Notes presented in Table A-6 of Appendix A.

Due to the variety of aircraft and engine types incorporated in the data bases, not all parameters were applicable for all aircraft. For example, the turbine inlet temperature does not apply to aircraft with a reciprocating engine. Thus, for selected aircraft certain parameters were omitted if a compatible substitution could not be found. A complete list of these omissions and substitutions is provided in Table A-7 of Appendix A.

These parameters were selected to permit prediction of notional aircraft MFHBF values early in the design phase. For this reason, many design/performance parameters normally not available early in an aircraft's evaluation were not incorporated in the Design/Performance Data Base. As a result, many of the detailed engineering characteristics, used to describe the aircraft, were not included in the two models.

A listing of all design/performance parameters with units are presented in Tables A-8 and A-9 of Appendix A for the fixed wing and rotary wing aircraft, respectively. These tables also indicate which parameters are used in at least one prediction equation, and indicate the minimum and maximum values for the parameters. Attempts to use notional design/performance values outside these limits require extrapolation with accompanying risk that the predicted MFHBF value may be unrealistic.

An attempt was made to reflect the change in aircraft technology by including two "date related" parameters in the fixed wing and three in the rotary wing data base. These were the "Date of 1st Flt. -- Prototype", "Date of 1st Flt. -- Series", and "Date of 1st Flt. -- Service". Some aircraft used in the study cover a time span beginning in the early 1950's and aircraft technology has changed significantly since then. Reference the General Notes, Table A-6 of Appendix A for details of their calculation, and Section 6.1.1 for a discussion of the results of their use in the prediction equations.

4.3.2 Additions and Refinements. In reviewing the preliminary results of prediction equation development it became evident that additional design/performance parameters were required for several WUC subsystems of the fixed wing aircraft model while the design/performance data for the rotary wing aircraft model appeared adequate. The initial Design/Performance Data Base for the fixed wing aircraft consisted of the first 75 design/performance parameters shown in Table A-8 of Appendix A. To improve the quality of the fixed wing equations, 20 additional parameters (76 through 95) were added to the Design/Performance Data Base.

Most of the additional parameters were engine related. Other parameters were either the squared value of an existing parameter or the ratio of two existing parameters. The remainder were binary indicator parameters which permit categorical differences between aircraft to be accounted for. These binary parameters are defined as "0" (not applicable) for one category and "1" (applicable) for the other category.

In an attempt to further improve the statistical quality of various prediction equations, six additional interaction term parameters (96 through 101) were introduced. These interaction parameters are formed by the product of an indicator parameter as it applies to a given aircraft and a design/performance parameter. See Sections 5.5 and 6.1.1 for a more detailed explanation of the use of indicator and interaction parameters.

5. TECHNICAL APPROACH

Statistical methods were used to derive the "best" functional relationship between the MFHBF and aircraft design/performance characteristics for each two-digit WUC subsystem included in the prediction models. In order to better appreciate the methodology adopted in development of the prediction equations, an understanding of the techniques employed in the analysis is necessary. An overview of these statistical methods and concepts, as they apply to the development of the Baseline Reliability Prediction Models, is presented in the following sections.

5.1 Regression Analysis. Regression analysis, a commonly used statistical technique, was the fundamental method used for development of the baseline MFHBF prediction equations. For these equations, the design/performance parameters served as the independent variables with the dependent variables being either the MFHBF or the natural log of the MFHBF, i.e., ln(MFHBF). A complete discussion concerning the use of ln(MFHBF) versus the MFHBF is presented in Section 6.2.

For this analysis, the true functional relationship between the independent and dependent variables is assumed to be linear; i.e., the equation is assumed linear in the coefficients of the independent variables. The linearity constraint restricts only the form of the coefficients. The independent variables can be any known functional form of other variables. For example, ratios, such as Max. Thrust to Max. Take-Off Weight, and cross products, such as (Max. Speed--Mach No.) x (Type A or B) are acceptable independent variables.

The primary goal of the regression analysis is to derive the "best" equation for prediction of the dependent variable. Thus, the functional relationship between the independent and dependent variables described by the equation is not one of "cause and effect". The only inference that can be made from the equation is that the independent variables have historically been good predictors of the dependent variable.

Mathematically, it was assumed that the MFHBF or ln(MFHBF) for a given two-digit WUC subsystem could be represented by the linear statistical model:

$$Y = \beta_0 + \sum_{j=1}^{p} \beta_j X_j + \varepsilon$$

where

Y is the dependent variable, i.e., the MFHBF or the ln(MFHBF)

$\beta_0, \beta_1, \ldots, \beta_p$ are unknown coefficients

$X_1, \ldots, X_p$ are independent variables, i.e., selected aircraft design/performance parameters,

and ε is the random error or error term.

Then an equation of the form

$$Y_i = \beta_0 + \sum_{j=1}^{p} \beta_j X_{ij} + \varepsilon_i$$

exists for the ith aircraft in the data base, i = 1, ..., n, so that a system of equations

$$\begin{aligned} Y_1 &= \beta_0 + \sum_{j=1}^{p} \beta_j X_{1j} + \varepsilon_1 \\ &\vdots \\ Y_n &= \beta_0 + \sum_{j=1}^{p} \beta_j X_{nj} + \varepsilon_n \end{aligned} \qquad (5.1)$$

is obtained. This system of equations can be solved to obtain estimates of β_0, β_1, ..., β_p, say b_0, b_1, ..., b_p. The MFHBF prediction equation then becomes

$$\hat{Y} = b_0 + \sum_{j=1}^{p} b_j X_j \tag{5.2}$$

where

$\hat{Y}$ is the predicted MFHBF or predicted ln(MFHBF).

If Y = MFHBF, the baseline MFHBF for a conceptual aircraft two-digit WUC subsystem can be predicted by substitution of its design/performance parameter values (the X_1, ..., X_p) into the prediction equation. If Y = ln(MFHBF), the exponential of $\hat{Y}$ must be computed before the predicted baseline MFHBF is obtained.

The initial solution to the system of equations was obtained by the method of least squares. The least squares technique derives as estimates of the β_i's, those values, b_i (i=1, ..., p), such that $\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$, the sum of squares of error, is minimized. In the case of a single independent variable, this equates to fitting a line to the data such that the sum of squares of the vertical distances from data points to the line is minimized.

In matrix notation, the system of equations in Equation (5.1) can be expressed as

$$\underline{Y} = \beta_0 \underline{1} + X\underline{\beta} + \underline{\varepsilon} \tag{5.3}$$

where

β_0 is an unknown coefficient,

$\underline{Y}$ is an nx1 vector of dependent variables,

$\underline{1}$ is an nx1 vector of 1's,

X is an nxp matrix of independent parameter values expressed as deviations from the mean,

$\underline{\beta}$ is the px1 vector of unknown coefficients, $\beta_1, \ldots, \beta_p$

and $\underline{\varepsilon}$ is an nx1 vector of the error terms. By minimizing

$$(\underline{Y} - \hat{\underline{Y}})'(\underline{Y} - \hat{\underline{Y}}) = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$$

where

$\hat{\underline{Y}} = b_0\underline{1} + X\underline{b}$, with respect to b_0 and $\underline{b}$ (estimates of

β_0 and $\underline{\beta}$, respectively), the least squares solutions are obtained; namely,

$$b_0 = \overline{Y} \tag{5.4}$$

and $\underline{b} = (X' X)^{-1} X' \underline{Y}$, where X' reads "X transpose".

Besides minimizing the sum of squares of error (SSE), there are several advantages associated with the use of least squares regression. One is the computational ease in obtaining the estimated coefficients b_i. Under the assumption that the error terms, ε_i, are normally distributed with mean zero and variance σ^2, the following properties can be derived:

- o b_i's are the Best Linear Unbiased Estimators (BLUE) of the β_i's.

- o b_i's are Maximum Likelihood Estimators (MLE'S) of the β_i's.

- Each $b_i (i = 0, 1, \ldots, p)$ is normally distributed.

- $\underline{b} = [b_1, b_2, \ldots, b_p]'$ is multivariate normal with mean $\underline{\beta}$ and variance-covariance matrix $(X' X)^{-1} \sigma^2$.

More important to the development of the Baseline Reliability Prediction Models is the fact that a basic problem often exists with the least squares coefficients. When two or more independent variables are highly correlated, the term "multicollinear" is used to describe the data. When the least squares technique is applied to multicollinear data, the resulting coefficient estimates are often "unstable". The addition or deletion of a single data point may significantly affect the magnitude and/or change the sign of coefficient estimates. These least squares estimates also result in poor predictions when using values for the independent variables which lie outside the range of the data base, and which is expected in predicting notional aircraft baseline MFHBF. For a more detailed discussion of multicollinearity see Section 5.6.

Due to the instability in the least squares coefficients, biased regression was used to derive most of the baseline MFHBF prediction equations. Biased regression techniques reduce the adverse effects of highly correlated variables and establish more stable coefficient estimates. Details of the biased techniques employed in the analysis are outlined in Section 5.6.

5.2 Measures of Fit to the Data. Given a prediction equation derived from a regression analysis, some measure of how well this equation fits the observed data is desirable. Two statistical measures, frequently used, are: (1)The coefficient of determination, R^2, and (2), the sum of squares of error, SSE.

The coefficient of determination is the fraction of the total variation in the data for the dependent variable, Y, accounted for by the prediction equation. The total variation, called the total sum of squares (TSS) is expressed as

$$TSS = \sum_{i=1}^{n}(Y_i - \overline{Y})^2 = \sum_{i=1}^{n}(\hat{Y}_i - \overline{Y})^2 + \sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$$

where

Y_i is the historical aircraft value for either the MFHBF or the ln(MFHBF), depending upon the form of the equation being developed,

$\overline{Y}$ is the mean of the Y_i's,

$\hat{Y}_i$ is the predicted value for Y_i derived from the prediction equation,

$\sum_{i=1}^{n}(\hat{Y}_i - \overline{Y})^2$ is the sum of squares acccounted for by the prediction equation; i.e., the sum of squares due to regression, SSR,

and $\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$ is the sum of squares of error, SSE.

The coefficient of determination, by definition, may be written:

$$R^2 = \frac{SSR}{TSS} = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \overline{Y})^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}$$

with $0 \leq R^2 \leq 1$. The closer R^2 is to 1, the better the fit of the equation to the data. Since the least squares solution to a system of equations for a fixed set of independent variables minimizes SSE, the least squares solution also maximizes R^2.

Historically, the coefficient of determination has often been used improperly. Through various manipulations, R^2 values ranging between 0 and 1 can be obtained for the same set of data. If the number of independent variables is increased and the number of data points is held constant, the value of R^2 will increase. By increasing the number of data points used to derive the prediction equation, R^2 can be systematically increased or decreased for a given set of independent variables.

More importantly, the value of R^2 is a good indicator of how well the prediction equation is able to predict only under specific conditions. If the historical data from which the equation is derived is "typical" and if the independent variable values applied to the prediction equation are contained within the data space of the historical variable values, R^2 provides an indication of the equation's predictive ability. Given the number of aircraft available for model development and the possible difference in range of some notional aircraft parameter values, the choice of final baseline MFHBF prediction equations should not be based on R^2 alone.

The sum of squares of error (SSE) is another quantity frequently examined in connection with the equation's fit to the data. As previously discussed this value is minimized for a fixed set of parameters by using the least squares coefficients. As with R^2, the most valid use of SSE is in determining which set of independent variables of equal size provides the "best" fit to the data. Given the number of data points and independent variables remain constant, the set of parameters associated with the equation for which SSE is minimized, provides the best fit.

One important difference between R^2 and SSE becomes apparent in a stepwise regression setting. As the system of equations becomes saturated with an increase in the number of independent variables at each step, the improvement in R^2 becomes increasingly small. At a given step, where a minimal increase in R^2 is shown, a substantial decrease in SSE can still be reflected. Thus, both SSE and R^2 require simultaneous examination in determining the equation's fit to the data.

5.3 <u>Stepwise Regression</u>. A variety of techniques have been developed for the selection of independent variables for use in regression analysis. Some of the more commonly used techniques include determination of an optimal subset, backward elimination, and forward selection.

Forward selection was the stepwise procedure used in development of the Baseline Reliability Prediction Models. This variable selection routine is especially well suited to regression analyses where the number of independent variables of interest is greater than the number of available data points. In the forward selection or "step-up" procedure, independent variables are introduced into the equation one at a time. At each step, the variable which produces the greatest increase in SSR, given the previously chosen variables are included in the equation, is added.

Suppose, for example, p independent variables are to be used to form a prediction equation. To choose p variables from a set of q (>p) possible variables:

Step 1: Compute SSR (X_i) (The sum of squares due to regression using one independent variable) for i = 1, 2, ..., q.
Find the maximum value of SSR (X_i).
Include the corresponding X_i in the prediction equation.

Step 2: Compute SSR ($X_i X_j$) for j = 1, 2, ... q, j ≠ i.
Find the maximum value of SSR ($X_i X_j$).
Include the corresponding X_j in the prediction equation.

Step 3: Compute SSR ($X_i X_j X_k$) for k = 1, 2, ..., q, k ≠ i, k ≠ j.

Find the maximum value of SSR ($X_i X_j X_k$).
Include the corresponding X_k in the prediction equation.

.
.
.

The process continues until Step p, where the last independent variable is chosen.

As with all stepwise techniques, the forward selection procedure has some shortcomings. First, the technique does not compensate for multicollinearities in the data. When two or more highly correlated variables exist in the data, often only one of the variables will be added to the prediction equation. In the Baseline Reliability Prediction Models, this may result in the selection of a less-logical parameter from an engineering standpoint. Secondly, once an independent variable has been chosen, no re-evaluation of this variable's relative contribution to the equation is made. Because of multicollinearities, as additional choices are made, the early selections often do little to enhance the prediction equation's fit of the data; that is, a different subset of the same size using other possible combinations of variables would form a "better" equation. Thus, the parameters chosen through the forward selection process may not form an optimal group of independent variables for equation development.

5.4 Correlation Analysis. In correlation analysis, the degree of linear association between the variables is determined. The primary statistic used in correlation analysis is the correlation coefficient, r. The correlation coefficient estimates the true degree of association between two variables, u and v, using the sample values (u_1, v_1), (u_2, v_2), (u_n, v_n).

Mathematically,

$$r = \frac{n\left(\sum_{i=1}^{n} u_i v_i\right) - \left(\sum_{i=1}^{n} u_i\right)\left(\sum_{i=1}^{n} v_i\right)}{\sqrt{\left[n\left(\sum_{i=1}^{n} u_i^2\right) - \left(\sum_{i=1}^{n} u_i\right)^2\right]\left[n\left(\sum_{i=1}^{n} v_i^2\right) - \left(\sum_{i=1}^{n} v_i\right)^2\right]}} \tag{5.5}$$

This statistic ranges in value from -1 to 1, inclusive. If the absolute value of r, $|r|$, is close to 1, the variables are said to be highly or strongly correlated. If $|r|$ is close to 0 the variables are said to be weakly correlated. For the simple linear prediction equation,

$$v = b_0 + b_1 u,$$

the value r^2 is precisely the coefficient of determination, R^2.

In development of the Baseline Reliability Prediction Models, correlation analysis was used to identify independent variables for which there was a strong degree of linear association. If the absolute value of the correlation between two independent variables, X_1 and X_2, is close to 1, these aircraft characteristics are considered to be "statistically equivalent". If both of these variables appear in the same prediction equation, the data is said to be multicollinear.

Correlation analysis was also used to identify aircraft characteristics which are potentially important predictors of the MFHBF or the ln(MFHBF). If the dependent variable, Y, and independent variable, X_i, are strongly correlated, X_i may be a good variable to include in the prediction equation. In the step-up regression procedure, the first independent variable chosen is the variable which is most highly correlated with Y.

Like R^2 and SSE, the implications of highly correlated variables need to be understood. The correlation coefficient measures only the degree of association between two variables and is not the foundation for a "cause and effect" argument.

Knowledge of the correlation between the dependent variable, Y, and each independent variable, X_i, alone does not indicate which independent variables will form the best prediction equation. In fact, the set of variables most highly correlated with Y is not likely to be the best set of independent variables for the prediction equation. Examination of only the correlation coefficients between Y and the X_i's does not take into account the relationships between the X_i's. It may be that some of the X_i's themselves are strongly correlated and the inclusion of all of the variables would be statistically redundant.

5.5 Indicator Variables and Interaction Terms. Two special types of independent variables, indicator variables and interaction terms, were used in the later stages of the development of the Baseline Reliability Prediction Models. While the use of these variables in a baseline MFHBF prediction equation is straight forward, their structure and purpose is somewhat different from the usual quantitative variable.

Indicator or "dummy" variables permit categorical differences between aircraft to be accounted for. Numerically, the dummy variable is binary; i.e., defined to be "0" for one category and "1" for the other category.

Mathematically, the use of an indicator variable results in two possible values for the leading constant of a given prediction equation. For example, suppose the final form of a prediction equation is

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \ldots. + b_pX_p$$

Let X_1 be an indicator variable defined as

$$X_1 = \begin{cases} 1, & \text{if the aircraft belongs to Category 1} \\ 0, & \text{if the aircraft belongs to Category 2} \end{cases}$$

with Categories 1 and 2 being dichotomous classifications for all aircraft under consideration. If, in applying the prediction equation, the aircraft belongs to Category 1, the equation becomes

$$\hat{Y} = (b_0 + b_1) + b_2X_2 \ldots. + b_pX_p.$$

Otherwise, the equation becomes

$$\hat{Y} = b_0 + b_2X_2 + \ldots. + b_pX_p.$$

In the case of a simple linear prediction model, these equations would appear graphically as parallel lines. Suppose, for instance, that the final baseline MFHBF prediction equation for WUC XX000 is

$$\hat{Y} = 13.56 - 6.22X_1 + 0.60X_2$$

where $\hat{Y}$ = MFHBF

$$X_1 = \begin{cases} 1, & \text{if the aircraft is Type B} \\ 0, & \text{if the aircraft is Type A} \end{cases}$$

X_2 = Minimum Combat Mission Time

Then, for Type B aircraft, the predicted value for the baseline MFHBF is obtained by substituting the minimum combat mission time into the equation

$$\begin{aligned} MFHBF &= (13.56 - 6.22) + 0.60 \times (\text{Min. Combat Mission Time}) \\ &= 7.34 + 0.60 \times (\text{Min. Combat Mission Time}) \end{aligned}$$

For Type A aircraft the prediction equation becomes

$$MFHBF = 13.56 + 0.60 \times (\text{Min. Combat Mission Time})$$

The graph of these prediction equations is shown in Figure 5-1.

In the Baseline Reliability Prediction Models, the distinction between marine assault and non-marine assault rotary wing aircraft and between Type A and Type B fixed wing aircraft, for example, were incorporated into selected baseline MFHBF prediction equations through the use of indicator variables.

An interaction term is used when the linear effect, i.e., the slope of a continuous or quantitative variable, X_2, is not the same for the two classifications of an indicator variable, X_1. The interaction term is formed by taking the product of the indicator variable, X_1, and the continuous variable, X_2. When an interaction term is used in a prediction equation, both the indicator variable and the continuous variable for which the linear effect di. ers also appear as independent variables.

By including an indicator variable and an interaction term in a prediction equation, two values for the leading constant and the coefficient of the quantitative variable, X_2, are possible. Suppose, for example, the final form of a prediction equation is

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_{1,2}X_1X_2 + b_3X_3 + \dots + b_pX_p$$

where

$$X_1 = \begin{Bmatrix} 1, \text{ if the aircraft belongs to Category 1} \\ \\ 0, \text{ if the aircraft belongs to Category 2} \end{Bmatrix} = \text{ indicator variable,}$$

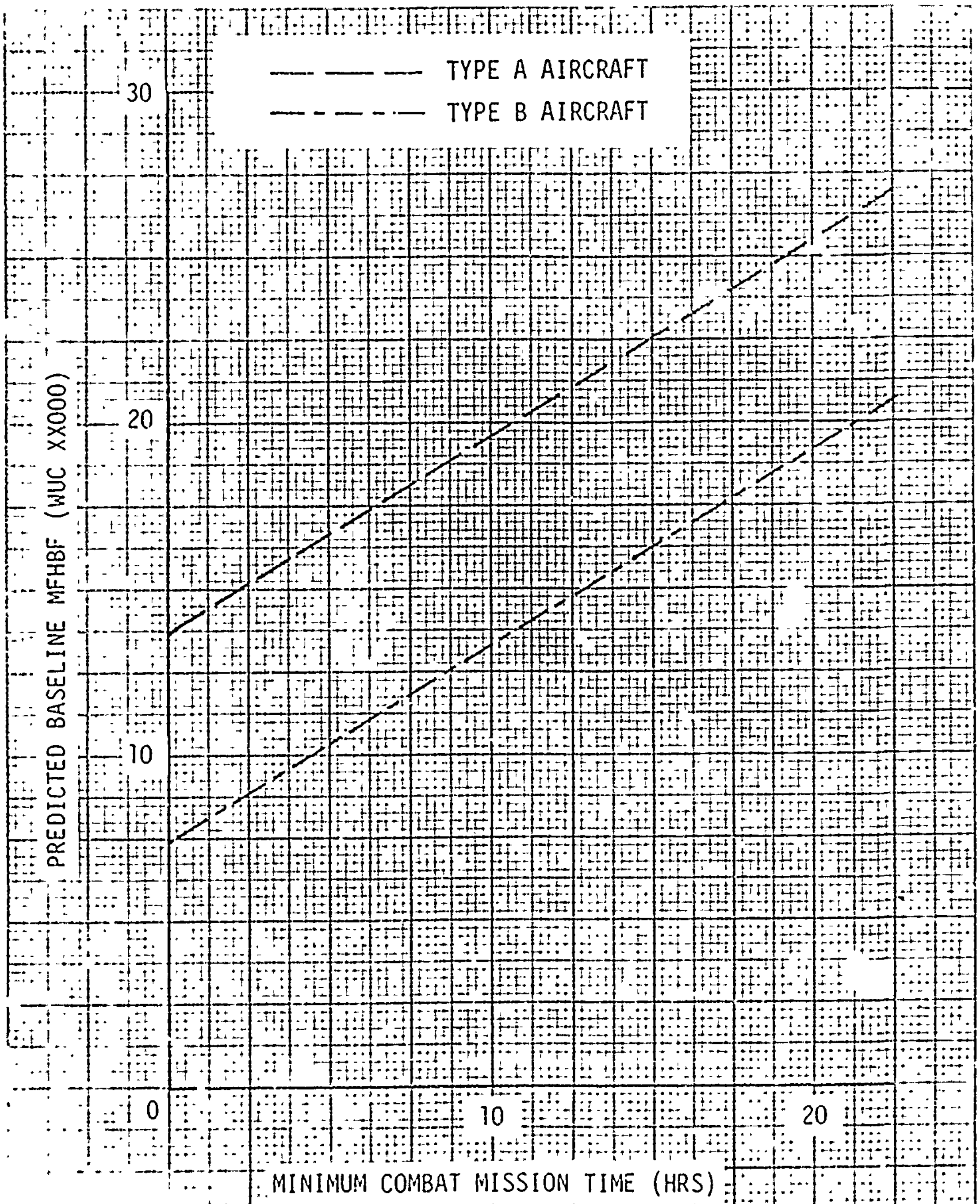

Figure 5-1. Graphical Representation of Indicator Variable Effects in a Prediction Equation

X_2 is a continuous independent variable,

and
$$X_1X_2 = \left\{\begin{array}{l} X_2, \text{ if the aircraft belongs to Category 1} \\ 0, \text{ if the aircraft belongs to Category 2} \end{array}\right\} = \text{interaction term.}$$

For an aircraft belonging to Category 1, the prediction equation becomes

$$\hat{Y} = (b_0 + b_1) + (b_2 + b_{1,2})X_2 + b_3X_3 + \ldots. + b_pX_p.$$

For an aircraft belonging to Category 2, the prediction equation becomes

$$\hat{Y} = b_0 + b_2X_2 + b_3X_3 + \ldots. + b_pX_p.$$

Thus, the constant in the equation is either $(b_0 + b_1)$ or b_0 and the coefficient of X_2 is either $(b_2 + b_{1,2})$ or b_2.

If only one continuous independent variable X_2 is used in the equation, i.e., $\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_{1,2}X_1X_2$, the equations would appear graphically as two lines with distinct slopes and intercepts. Continuing with the previous numerical example, suppose the baseline MFHBF prediction equation for WUC XX000 is

$$\hat{Y} = 13.56 - 6.22X_1 + 0.60X_2 + 0.45X_1X_2.$$

Then

$$\hat{Y} = \text{MFHBF},$$

$$X_1 = \begin{cases} 1, \text{ if the aircraft is Type B} \\ 0, \text{ if the aircraft is Type A,} \end{cases}$$

$$X_2 = \text{Minimum Combat Mission Time,}$$

and

$$X_1X_2 = \begin{cases} X_2, \text{ if the aircraft is Type B} \\ 0, \text{ if the aircraft is Type A.} \end{cases}$$

For Type B aircraft, the predicted baseline MFHBF is obtained by substitution of the minimum combat mission time into the equation

$$\text{MFHBF} = (13.56 - 6.22) + (0.60 + 0.45) \times (\text{Min. Combat Mission Time})$$
$$= 7.34 + 1.05 \times (\text{Min. Combat Mission Time})$$

For Type A aircraft, the predicted baseline MFHBF is obtained from the equation

$$\text{MFHBF} = 13.56 + 0.60 \times (\text{Min. Combat Mission Time}).$$

Figure 5-2 graphically displays these two prediction equations.

In the above discussion, the most simple use of these variables was presented. In more complex situations, more than one indicator variable and/or interaction term will appear in the prediction equation. While the continuous variable, X_2, must be present when the associated interaction term is used in an equation, the indicator variable is not required. Without the indicator variable present, two equations with different slopes and a common intercept will be formed.

The use of these variables should be restricted to situations where there is a clear indication for their need. The required increase in the number of independent variables for the equation will sometimes prohibit the use of these terms. When very little data is available for development of a prediction equation, it is unlikely that two distinct trends in the data will be apparent. Because the interaction term and continuous variable are highly correlated, multicollinear data will result from the inclusion of the interaction term.

5.6 <u>Multicollinearities and Biased Regression</u>. Multicollinearity has already been identified in earlier discussions of other regression analysis techniques as a potential source of many problems. Therefore, the questions which need to be addressed are: (1) "What does it mean for the data to be multicollinear?", (2) "How do you detect multicollinearities?"; and (3) "What do you do about them?"

A multicollinearity is said to exist if any independent variable is nearly

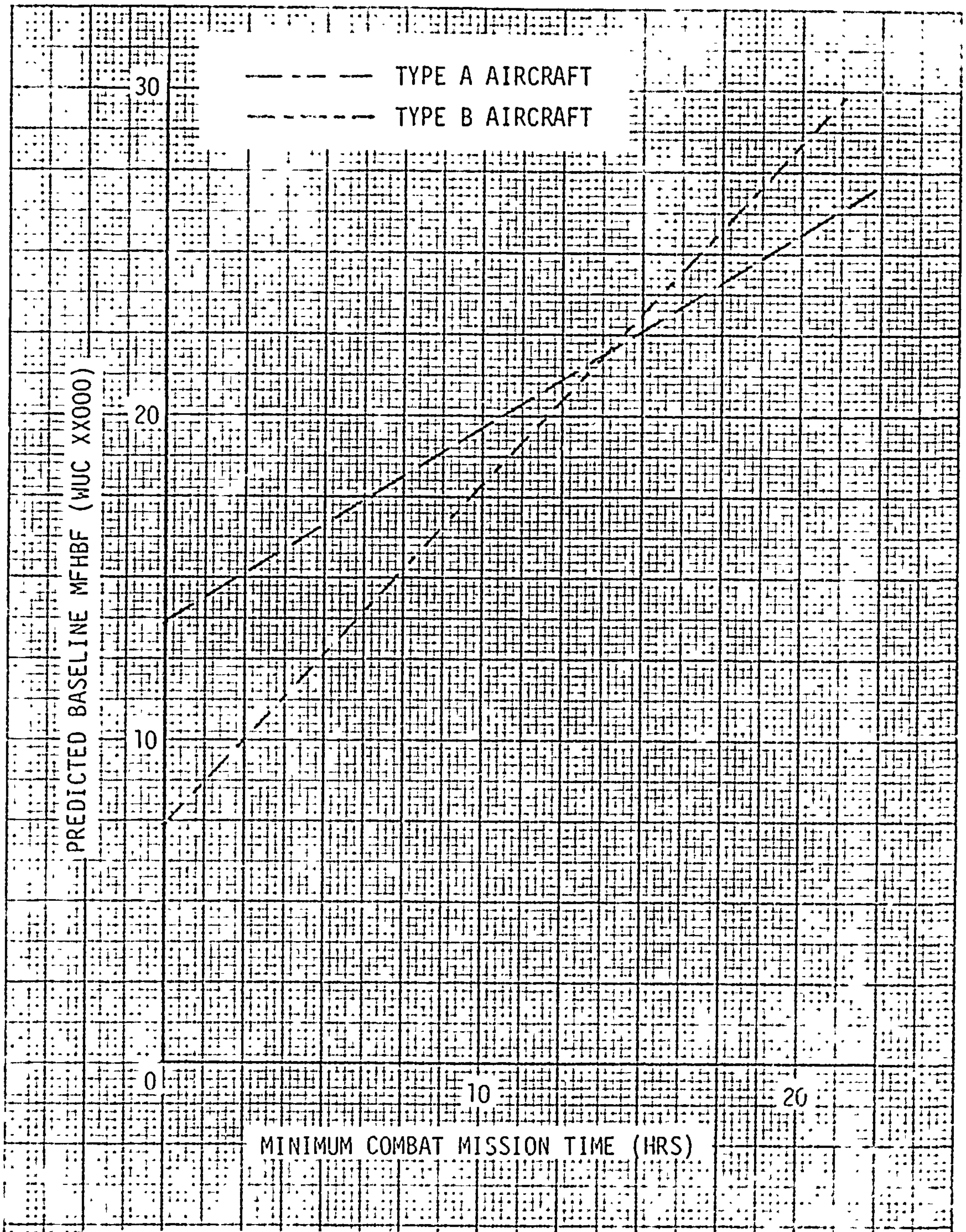

Figure 5-2. Graphical Representation of Indicator Variable and Interaction Term Effects in a Prediction Equation

a linear function of other independent variables in a regression model. That is, given the statistical model

$$Y = \beta_0 + \sum_{j=1}^{p} \beta_j X_j + \varepsilon,$$

there exists a set of constants a_ℓ, $\ell=1, \ldots., p$, not all zero, such that

$$X_j \approx \sum_{\substack{\ell=1 \\ \ell \neq j}}^{p} a_\ell X_\ell$$

for some $j = 1, \ldots., p$. Applying this notation to the system of equations in Equation (5.1),

$$X_{ij} \approx \sum_{\substack{\ell=1 \\ \ell \neq j}}^{p} a_\ell X_{i\ell} \text{ for } i=1, \ldots, n ,$$

or

$$\underline{X}_j \approx \sum_{\substack{\ell=1 \\ \ell \neq j}}^{p} a_\ell \underline{X}_\ell \qquad (5.6)$$

where

$$\underline{X}_j = \begin{bmatrix} X_{1j} \\ \vdots \\ X_{nj} \end{bmatrix} \text{ and } \underline{X}_\ell = \begin{bmatrix} X_{1\ell} \\ \vdots \\ X_{n\ell} \end{bmatrix} .$$

An equivalent expression for Equation (5.6) would be

$$\sum_{j=1}^{p} a_j \underline{X}_j = \underline{0}, \text{ where } \underline{0} \text{ is the null vector.}$$

Recalling the matrix notation of Equation (5.2) for the system of equations, this implies

$$X\underline{a} \approx \underline{0}, \text{ where } \underline{a} = [a_1, a_2, \ldots, a_p]' \, .$$

Premultiplying by the transpose of $X\underline{a}$,

$$\underline{a}' X'X\underline{a} \approx \underline{0}, \text{ which implies } X'X\underline{a} \approx \underline{0} \, .$$

Recalling the relationship between latent roots and latent vectors, $X'X\underline{a} = \lambda_j\underline{a}$, it follows that $X'X$ has a very small latent root, λ_j.

As discussed in Section 5.1, the least squares estimate of β, the vector of coefficients for the model, is given by $\underline{b} = (X'X)^{-1} X'\underline{Y}$. The variance-covariance matrix of the coefficient estimates, $\mathrm{Var}(\underline{b}) = (X'X)^{-1}\sigma^2$. Rewriting $X'Y$ in terms of its latent roots and vectors, $X'X = C\Lambda C'$ where $C = [\underline{C}_1, \ldots \underline{C}_p]$ is a pxp matrix of the normalized latent vectors of $X'X$ and Λ is a diagonal matrix of the latent roots of $X'X$. Then

$$(X'X)^{-1} = (C\Lambda C')^{-1} = C\Lambda^{-1}C' = \sum_{j=1}^{p} \frac{1}{\lambda j} \underline{C}_j \underline{C}_j' \, .$$

Using this form for the variance-covariance matrix,

$$\mathrm{Var}(\underline{b}) = \sigma^2 \sum_{j=1}^{p} \frac{1}{\lambda_j} \underline{C}_j \underline{C}_j' \tag{5.7}$$

$$\mathrm{Var}(b_i) = \sigma^2 \sum_{j=1}^{p} \frac{C_{ij}^2}{\lambda_j} \, , \quad \text{for } i=1, \ldots, p \, .$$

So if λ_j is small, at least one of the estimated coefficients, b_i, will have a large variance.

Thus, the presence of multicollinearity in the data implies that at least one "near perfect" linear relationship exists between two or more independent variables. These relationships result in the matrix $X'X$ having small latent roots, one for each multicollinearity. In turn, these small latent roots result in large variances for some of the least squares estimates of the β_i's.

Because the b_i's have such large variance, often these coefficients are poor estimates of their respective β_i's. The estimated coefficients may even have the wrong sign. If the prediction equation is used for extrapolation, the predicted value of Y, $\hat{Y}$, is likely to be unreasonable. The large variance creates such instability that the addition or deletion of a single data point can result in a significant change in the magnitude and/or sign of the coefficient.

A variety of techniques are used to detect the presence of multicollinearities. Correlation coefficients identify simple pairwise multicollinearities; that is, multicollinearities of the form, $X_j \approx a_k X_k$, where X_j and X_k are independent variables and a_k is a non-zero constant. If X_j and X_k are highly correlated, then they are also said to be multicollinear. More complex relationships are not always apparent from the use of correlation analysis.

Examination of the latent roots and latent vectors of $X'X$ provide the best and most complete diagnosis of multicollinearities. If a latent root λ_j is small, the corresponding latent vector $\underline{C}_j$ tells which variables are involved based on the magnitude of each element in the latent vector. As the number of independent variables increases, the latent vector is almost impossible to interpret.

Still another technique makes use of the matrix $(X'X)^{-1}$ itself. Recalling that $(X'X)^{-1}\sigma^2$ is the variance-covariance matrix of the vector of coefficients, $\underline{b}$, the diagonal elements of $(X'X)^{-1}$ are a multiple of the variances of the b_i's. These diagonal elements, referred to as the Variance Inflation Factors (VIF's), indicate not only which X_i are involved in a multicollinearity, but also which β_i may be poorly estimated. More precisely, if the ith diagonal element of $(X'X)^{-1}$ is large, then X_i is involved in a multicollinearity; and if X_i is involved in a multicollinearity, then b_i may be a poor estimate of β_i. The VIF's do not reveal which combination of variables actually form the multicollinearities.

In the forward selection of variables, the addition of a variable involved in a multicollinearity with the previously selected variables is reflected in the t-statistics for each independent variable of the equation. Any radical change in the relative size of the t-statistics, from the previous step, would indicate an independent variable's involvement in a multicollinearity. As this indication is only a byproduct of the selection process, this form of analysis is only partial. Often variables which are highly correlated with the previously selected variables will not even be entered into the prediction equation.

The course of action taken in the case of multicollinear data depends on both the nature of the multicollinearities and the ultimate use of the prediction equation. It has been shown that, provided the prediction equation is used with data which remains within the range of that used to derive the coefficients, there is no problem in using the least squares coefficients. In other words, the least squares prediction equation predicts well using data values similar to those used for equation development. If extrapolation is likely, it is sometimes possible to eliminate the multicollinearity by dropping the related variables from the equation. If the form of the multicollinearity is simple, i.e., $X_i \approx a_j X_j$, elimination of one of the variables will enable better estimates of the coefficients to be obtained If the form is more complex, elimination of all related variables will not only reduce the number of independent variables substantially, but also the quality of the fit to the data. In other situations, the multicollinearity is "built in". For example, if an interaction term is used, the associated independent variable will also appear in the equation. The two variables will be highly correlated and neither can be dropped from the equation. When physical or mathematical constraints necessitate the use of multicollinear independent variables, biased estimation is the best means of dealing with the multicollinearity.

Biased estimation procedures address the problem of poor estimates which result from multicollinear data. These procedures minimize the effect of linear relationships among the independent variables and develop a set of stable coefficient estimates. Through the use of biased regression, biased estimates of the β_i's are obtained which have reduced variances. Figure 5-3 shows the nature of the differences between the least squares or unbiased estimate of $\beta_i(b_i)$ and the biased estimate of $\beta_i(b^*_i)$ with respect to their distributions. With the decreased variance, the biased estimates are more stable and better for predicting outside the range of the data base.

Mathematically, the biased techniques involve artificially manipulating the λ_j's, the latent roots of the matrix, X'X. Recalling that X'X can be expressed as $C\Lambda C'$ where $C = [\underline{C}_1, \ldots, \underline{C}_p]$ is the matrix of normalized latent vectors and Λ is a diagonal matrix of latent roots, λ_j, $X'X=C\Lambda C'$ is replaced with $(X'X)^* = C\Lambda^* C'$ where Λ^* is a diagonal matrix of adjusted latent roots, λ^*_j. The vector of the coefficient estimates then becomes

$$\underline{b}^* = [(X'X)^*]^{-1} X'\underline{Y} \tag{5.8}$$

versus

$$\underline{b} = (X'X)^{-1} X'\underline{Y} \text{ which is the least square estimate } \underline{\beta}.$$

It can be shown that the variance-covariance matrix of $\underline{b}^*$ is

$$\mathrm{Var}(\underline{b}^*) = \sigma^2 \sum_{j=1}^{p} \frac{\lambda_j}{(\lambda^*_j)^2} \underline{C}_j \underline{C}_j' \, . \tag{5.9}$$

Equation (5.7) has shown the variance-covariance matrix of $\underline{b}$ to be:

$$\mathrm{Var}(b) = \sigma^2 \sum_{j=1}^{p} \frac{1}{\lambda_j} \underline{C}_j \underline{C}_j' \, .$$

So if $\lambda_j^* > \lambda_j$ for all λ_j, then for $i = 1, \ldots, p$,

$$\mathrm{Var}(b_i^*) \leq \mathrm{Var}(b_i),$$

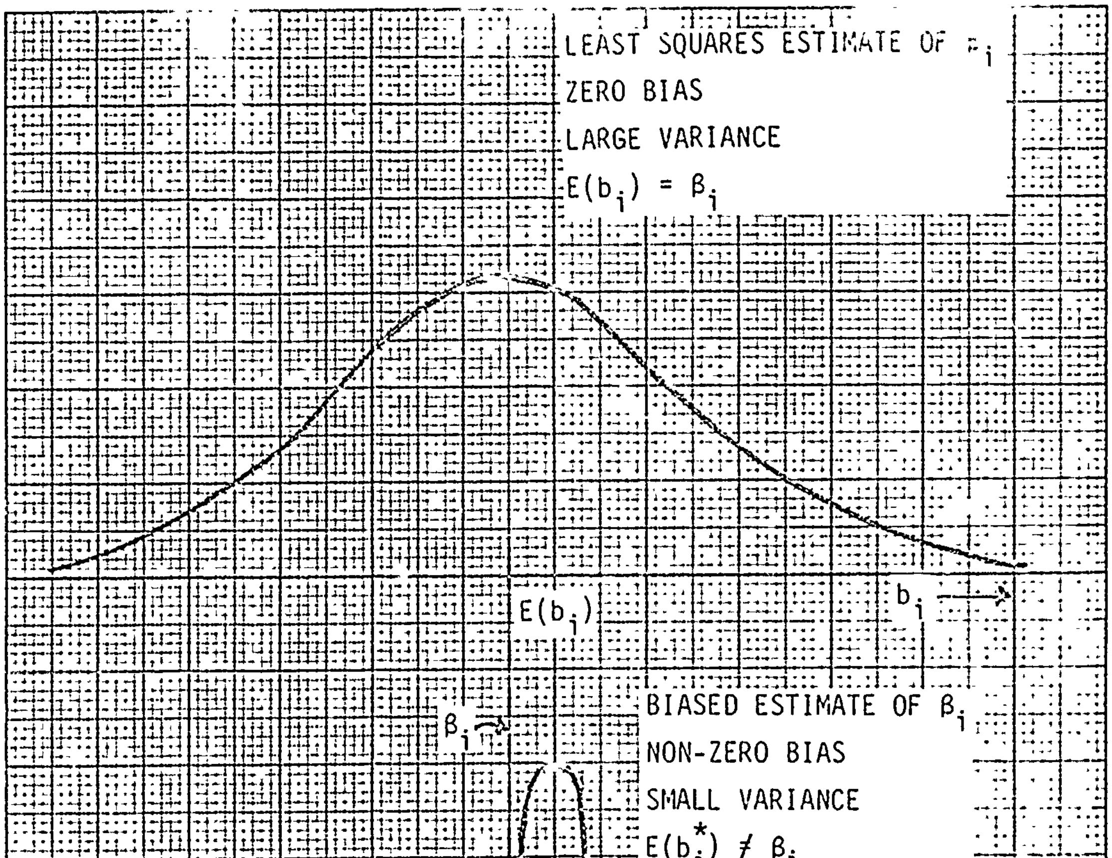

Figure 5-3. Variance and Bias of an Estimator of β_i

where

$\text{Var}\ (b_i^*)$ is the ith diagonal element of $\text{Var}\ (\underline{b}^*)$

and $\text{Var}\ (b_i)$ is the ith diagonal element of $\text{Var}\ (\underline{b})$.

To find an expression for the bias of $\underline{b}^*$, a change in notation is required. Since the latent vectors of X'X, the $\underline{C}_j$'s, form a basis in p-space, an equivalent expression for the vector of unknown coefficients is

$$\underline{\beta} = \sum_{j=1}^{p} \alpha_j \underline{C}_j \text{ , where the } \alpha_j \text{ are appropriately chosen constants.}$$

Then the expected value of $\underline{b}^*$ can be expressed as

$$E(b^*) = \sum_{j=1}^{p} \frac{\lambda_j}{\lambda^*_j} \alpha_j \underline{C}_j \tag{5.10}$$

So, the bias of $\underline{b}^*$,

$$\begin{aligned} \text{Bias}\ (\underline{b}^*) &= \underline{\beta} - E(\underline{b}^*) \\ &= \sum_{j=1}^{p} \left(1 - \frac{\lambda_j}{\lambda_j^*} \right) \alpha_j \underline{C}_j \end{aligned} \tag{5.11}$$

It follows then that if $\lambda_j^* = \lambda_j$, as in the least squares estimates, the $\text{Bias}\ (\underline{b}^*) = \text{Bias}\ (\underline{b}) = 0$. This again points out that the least squares estimates are also unbiased estimates.

Important relationships exist between the λ_j^*'s and the bias of the b_i^*'s. As the size of the λ_j^*'s increase, the variance of the b_i^*'s decrease, while the bias of the b_i^*'s increase. Thus, large values for the λ_j^*'s will produce as small a variance as desired; but this will happen at the cost of an excessive amount of bias in the estimates of the coefficients. Because of the bias, the difference between the values of the λ^*_j's used in practice and the latent roots, the λ_j's, is relatively small.

The specific type of biased estimator used in the de[illegible]ent of the

Baseline Reliability Prediction Models was the ridge estimator. Ridge regression, which has been widely used throughout industry, requires the use of only one additional parameter, k. The specific choice of k depends on the degree of multicollinearity in the data. The precise form of the ridge estimator, $\tilde{\underline{b}}$, is

$$\tilde{\underline{b}} = (X'X + kI)^{-1} X'\underline{Y},$$

where X and $\underline{Y}$ are as defined in Equation (5.3),

I is the pxp identity matrix,

and k is a constant, $k \geq 0$.

Comparing this with the least squares estimator, $\underline{b}$, X'X has been replaced by (X'X + kI). Recall that an alternative expression for X'X is $C\Lambda C'$, and since C is a matrix of the normalized latent vectors of X'X, CC' = I. Thus

$$X'X + kI = C\Lambda C' + kCC' = C[\Lambda + kI]C' = C\Lambda^{*}C' = (X'X)^{*}$$

where $\Lambda^{*} = \Lambda + kI$.

This implies that the ridge estimator

$$\tilde{\underline{b}} = (X'X + kI)^{-1} X'\underline{Y}$$

is simply a special case of the general biased estimator

$$\underline{b}^{*} = [(X'X)^{*}]^{-1} X'\underline{Y}.$$

As the diagonal matrix $\Lambda^{*} = \Lambda + kI$ for the ridge estimator, the adjusted latent roots, λ^{*}_{j}, are equal to the latent roots of X'X plus a constant; i.e., $\lambda^{*}_{j} = \lambda_j + k$ for j = 1, ..., p.

Substituting $\lambda^{*}_{j} = \lambda_j + k$ into Equations (5.9), (5.10) and (5.11), it immediately follows that the variance-covariance matrix of $\tilde{\underline{b}}$ is

$$\mathrm{Var}(\tilde{\underline{b}}) = \sigma^2 \sum_{j=1}^{p} \frac{\lambda_j}{(\lambda_j + k)^2} \underline{C}_j \underline{C}'_j \, ,$$

the expected value of $\tilde{\underline{b}}$ is

$$E(\tilde{\underline{b}}) = \sum_{j=1}^{p} \frac{\lambda_j}{\lambda_j + k} \alpha_j \underline{C}_j ,$$

and the bias of $\tilde{\underline{b}}$ is

$$\mathrm{Bias}\,(\tilde{\underline{b}}) = \sum_{j=1}^{p} \frac{k}{\lambda_j + k} \alpha_j \underline{C}_j \, .$$

Just as the ridge estimator can be thought of as a special case of the biased estimator, the least squares estimator can be thought of as a special case of the ridge estimator; namely, when $k = 0$.

The procedure followed in ridge regression calls for determining an appropriate value for k. This is done through examination of the ridge estimators for various choices of k. The usual procedure is to determine the smallest value of k for which the coefficient estimates have stabilized. Since the bias increases as $\lambda_j^* = \lambda_j + k$ increases, the smallest value of k will add the least amount of bias to the estimates. If the homogeneity of the data is in question, a larger choice of k is often used to provide additional stability to the coefficients.

The most widely used procedure for determining k involves a ridge trace. A ridge trace is a graph of the standardized coefficient estimates of the prediction equation for various values of k, starting with $k = 0$, or the least squares estimates. The point at which the relative change in the standardized coefficients is considered minor; i.e., the coefficients have stabilized, determines the choice for the value of k. Figure 5-4 shows the ridge trace for the coefficients of the independent variables used in the final baseline MFHBF prediction equation of WUC 61000 for fixed wing aircraft.

The amount of change in the standardized coefficient values, as k increases, depends upon the degree of multicollinearity in the data. If the data is highly multicollinear, a radical change in the standardized coefficients will occur, resulting in a relatively large value of k. If the data is only slightly multicollinear, very little change will occur, resulting in a very small value of k.

While examination of the ridge trace is the most widely used approach to determining k, the time involved in graphing the standardized coefficients is prohibitive when many independent variable combinations are to be considered. Therefore, a more quantitative approach to choosing k was used in developing the baseline MFHBF prediction equations.

One quantitative approach involved the use of the Variance Inflation

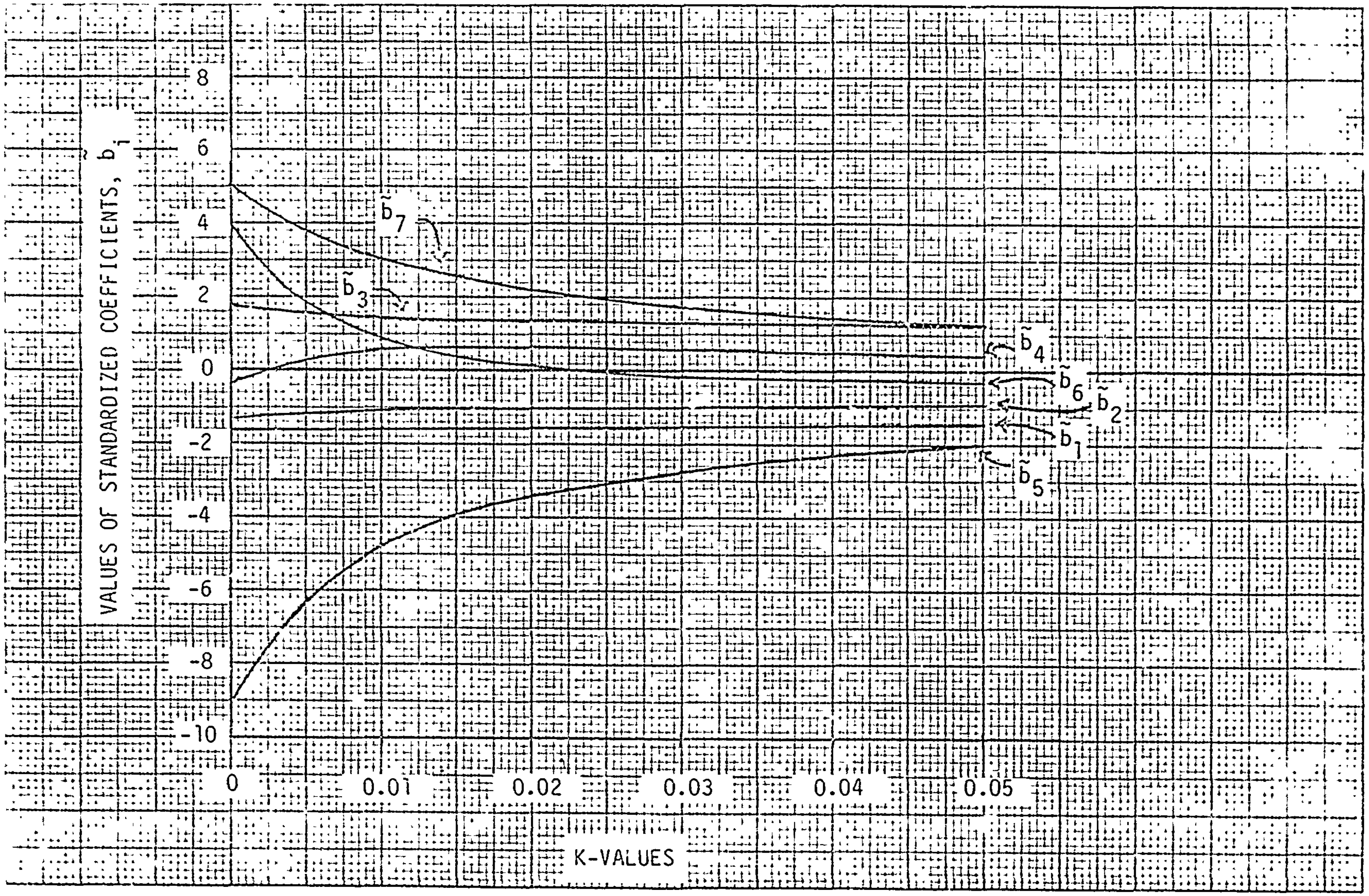

Figure 5-4. Ridge Trace - WUC 61000 For Fixed Wing Aircraft

Factors (VIF's) associated with each of the coefficient estimates. In the discussion of multicollinearities, the Variance Inflation Factors were described as indicators of the presence of multicollinear data. This utilization of the VIF's can be extended to assist in the choice of k. In a ridge regression setting the VIF's are used as indicators of the stability of the estimates for a given choice of k.

A substantial amount of research has been done concerning the use of the VIF's for determining k. The results indicate that if the maximum Variance Inflation Factor, associated with the ridge estimates for a given k, is less than or equal to ten, the coefficients are sufficiently stable. The general procedure is to examine the VIF's of the ridge coefficient estimates for various values of k. The smallest k, for which all VIF's are less than or equal to ten, is the appropriate choice for k.

In Table 5-1, the Variance Inflation Factors corresponding to the coefficients of the ridge trace (Figure 5-4) are presented. By choosing k = 0.015, using the VIF criteria, a reasonable degree of stability in the coefficients is achieved, as shown in the ridge trace.

Another alternative to the use of the ridge trace involves calculating the choice of k. This computed k-value is used when the set of data used for development of the equation may not be homogenous. The philosophy is that a larger value of k should be used because of the greater variation in the data. The choice of a larger k will add additional stability to the coefficients, which should offset the variation in the data. So, given a less compatible set of data points, reasonable predictions can still be obtained.

The formula for computing k is:

$$k = \frac{p\hat{\sigma}^2}{\sum_{i=1}^{p} b_i^2} \qquad (5.12)$$

where b_i, for i = 1 ...., p, is the standardized least squares estimate for

TABLE 5-1. VARIANCE INFLATION FACTORS FOR k = .0000 THROUGH .0225 FOR BASELINE MFHBF PREDICTION EQUATION - WUC 61000 FOR FIXED WING AIRCRAFT

STANDARDIZED COEFFICIENT ESTIMATE	VARIANCE INFLATION FACTORS				
	k = .0000	k = .0025	k = .0050	k = .0075	k = .0100
$\tilde{b}_1$	1.124	1.115	1.106	1.098	1.090
$\tilde{b}_2$	1.967	1.897	1.852	1.817	1.787
$\tilde{b}_3$	2.340	2.072	1.928	1.837	1.771
$\tilde{b}_4$	20.832	15.033	11.831	9.770	8.316
$\tilde{b}_5$	59.948	36.475	25.042	18.532	14.427
$\tilde{b}_6$	61.202	36.838	25.042	18.375	14.198
$\tilde{b}_7$	18.621	13.235	10.319	8.476	7.193

STANDARDIZED COEFFICIENT ESTIMATE	VARIANCE INFLATION FACTORS				
	k = .0125	k = .0150	k = .0175	k = .0200	k = .0225
$\tilde{b}_1$	1.083	1.076	1.069	1.062	1.055
$\tilde{b}_2$	1.760	1.736	1.712	1.690	1.668
$\tilde{b}_3$	1.721	1.679	1.643	1.612	1.583
$\tilde{b}_4$	7.227	6.377	5.694	5.134	4.665
$\tilde{b}_5$	11.644	9.655	8.175	7.037	6.140
$\tilde{b}_6$	11.387	9.392	7.916	6.788	5.905
$\tilde{b}_7$	6.249	5.510	4.925	4.447	4.049

β_i, p is the number of independent variables used in the equation, and $\hat{\sigma}^2$ is the estimator for the variance, σ^2. In general, as the data becomes less homogeneous or the equation's fit to the data becomes worse, the larger the value of the computed k. If, however, the number of independent variables used in the prediction equation is small relative to the number of data points, the computed k-value is sometimes found to be unreasonably large or small. To avoid the use of an unreasonable value for k, the k-value chosen using the VIF rule should also be examined.

Ridge regression effectively accomplishes the purpose for which it was designed; namely, to reduce the effect of multicollinearities through estimated coefficients with smaller variance. This gain in the stability of the coefficients, however, is not without cost. The use of ridge or any biased technique will result in an increase in the sum of squares for error, SSE, and a decrease in the coefficient of determination, R^2. Since these two statistics measure the optimal properties of a least squares solution, this is not surprising. Provided the decrease in R^2 and increase in SSE are not excessive, the additional predictive ability obtained from the biased equation is usually worth the sacrifice in these two measurements.

6. PREDICTION MODEL DERIVATION

Investigation of the functional form of each equation, the aircraft characteristics chosen as predictor variables, the historical aircraft used to derive the equations, and the method of estimating coefficients was required during development of the prediction models. The discussion in Section 6.1 pertains to the formulation and development of the models to their final form. Sections 6.2, 6.3, and 6.4 present procedures used throughout the development to arrive at the equations which form the Baseline Reliability Prediction Models.

6.1 Model Concept Formulation and Development.

The Baseline Reliability Prediction Models were developed to predict the MFHBF of notional aircraft. It was determined at the outset that each model would consist of a set of prediction equations. These equations would predict the baseline MFHBF at a two-digit WUC level. While the predictions would be combined mathematically to obtain an overall prediction of the notional aircraft MFHBF, prediction at a two-digit WUC level was chosen for two reasons: (1) At the two-digit WUC level, the models would be more responsive to different notional aircraft configurations; and (2) with about 35 two-digit WUC subsystems per notional aircraft, the prediction of the aircraft MFHBF would be less sensitive to inaccuracies in the predicted values for some of the two-digit WUC subsystems.

The original study effort called for the development of a prediction model for only fixed wing aircraft. This effort was later expanded to include the rotary wing aircraft by the exercising of a proposed option. The fixed wing aircraft prediction model was completed prior to deriving the rotary wing aircraft prediction model. The historical rotary wing aircraft used in model development formed a small homogeneous group of aircraft, while the larger group of fixed wing aircraft was composed of a variety of configurations. The nature of the historical aircraft used in model development and the timing of the efforts led to different rationale surrounding the formulation of each model.

6.1.1 Formulation of Fixed Wing Aircraft Model.

Initially, the development of a set of two-digit WUC prediction equations for each mission variant was considered; however, this idea had many shortcomings. Due to the small number of historical aircraft for certain mission variants, the prediction equations for these mission variants could have included only one aircraft characteristic in each equation. In addition, more than 280 prediction equations would have been required to predict the MFHBF for all the fixed wing aircraft.

It was decided instead to divide the fixed wing aircraft by mission variant into three groups. The three aircraft groups formed, Type A, Type B, and Type L, and the aircraft included in each group are given in Table 6-1. The Type A and Type B aircraft were all carrier-based, and the Type L aircraft were land-based.

By grouping the fixed wing aircraft, a larger number of historical MFHBF values would be used to derive the prediction equations. In turn, more predictor variables could be used to form each two-digit WUC prediction equation. A decision as to whether separate models for each aircraft group, or a single model for all fixed wing aircraft, would be developed depended primarily on the analysis of the data.

Given the time required to develop the Design/Performance Data Base for all 32 historical fixed wing aircraft selected for use in model development, a set of baseline MFHBF prediction equations were developed first using completed information on the Type B aircraft. This group of 19 aircraft included all the fighter, attack, electronic warfare, and reconnaissance aircraft being considered.

Even though any analysis performed might need to be repeated when the data for the remaining aircraft became available, consideration of only the Type B aircraft was felt to be worthwhile. Through the development of Type B prediction equations, the general adequacy of the Design/Performance Data Base characteristics as predictor variables was determined; potential difficulties associated with a shortage of MFHBF data for certain two-digit WUC's became apparent; and various analytical techniques and statistical procedures were investigated for use in the remainder of the study.

Numerous equations were derived and analyzed, before the final Type B

TABLE 6-1. FIXED WING AIRCRAFT USED IN MODEL DERIVATION BY TYPE AND MISSION VARIANT

TYPE A	TYPE B	TYPE L
Airborne Early Warning	Fighter	Patrol ASW
E-1B E-2B, C	F-4J, N F-14A	P-3A, B, C
Antisubmarine Warfare	Attack	Tanker
S-3A	A-4E, F, M A-6A, E A-7A, B, C, E AV-8A	KC-130F, R
COD Transport	Reconnaissance	
C-1A C-2A	RF-4B RF-8G RA-5C	
Tanker	Electronic Warfare	
KA-3B KA-6D	EA-3B EA-6A, B	

prediction equations for 27 of the 38 two-digit WUC subsystems for fixed wing aircraft were selected. The selection of predictor variables, for each two-digit WUC prediction equation, was made as described in Section 6.3. The appropriateness of developing a Type B aircraft MFHBF prediction equation to predict the ln(MFHBF) versus the MFHBF was determined for each two-digit WUC, as discussed in Section 6.2. In most cases, the equations were a good fit to the historical data, and had good predictive ability.

The one area of concern in the Type B model was in the prediction equations for the engines. These equations, which predicted the MFHBF on a per engine basis, were considered less than adequate. Few of the variables associated with engine performance or design appeared as good predictors of the reliability of the engine. The details of the study are presented in Section 6.1.2.

Through the derivation of the Type B aircraft MFHBF prediction equations, it was discovered that some aircraft parameters acted as a proxy for aircraft characteristics not contained in the data base. For example, the Number of Wing Plus Tail Folds of the fixed wing aircraft was shown to be an important predictor variable of the MFHBF for WUC 14000 and WUC 45000. This characteristic may be a reasonable choice as a variable for predicting the MFHBF of the Flight Controls (WUC 14000); however, the Number of Wing Plus Tail Folds is seemingly unrelated to the failures of the Hydraulic and Pneumatic Power (WUC 45000). A more appropriate interpretation of the variable, as it relates to WUC 45000, concerns the complexity of the Type B fixed wing aircraft. That is, the Number of Wing Plus Tail Folds is acting as a measure of the aircraft's complexity, which was an important factor in predicting the MFHBF.

In an effort to account for advancements in technology, the dates of the first flight for the prototype and series of the aircraft were used as predictor variables for the Type B prediction equations. They were found to be good predictors of the historical MFHBF for many WUC's. The prediction equations which used these dates as a variable, however, had poor predictive ability when used by NAVAIR to predict for notional aircraft. The approximate prototype and series dates of the notional aircraft were, of course, well outside the range of dates for the historical aircraft. When the future dates were multiplied by coefficients calculated using the historical aircraft dates, and combined with the other terms of the equation, the predicted baseline MFHBF for the WUC fell outside reasonable expectations.

As the MFHBF Data Base was studied in more detail, it was seen that, for certain WUC's, separate baseline MFHBF prediction equations for each of the aircraft groups would not be feasible. As shown in Table 6-2, a limited number of historical MFHBF values were available in certain groups for various WUC's. This would make development of separate prediction equations difficult. Anticipating the need for combined equations, Type B prediction equations were not developed for eleven of the two-digit WUC subsystems.

When the Design/Performance Data Base information was complete, the precise form for the fixed wing aircraft model was considered. For those WUC's where a limited number of historical MFHBF values were available for equation development, a single prediction equation was derived for predicting the MFHBF. For the remaining WUC's, a decision was required as to whether separate equations for each aircraft group or a single equation for combined aircraft groups would be developed.

The principal concern, with either form of equation development, was the compatibility and consistency of the data for the different aircraft groups. To measure the compatibility and consistency, the correlation coefficients of the design/performances parameters with the MFHBF or ln(MFHBF) for selected WUC's were determined for Type A, Type B, Type A and B combined, and Type A, B, and L combined. In Tables 6-3 and 6-4, the correlations of the design/performance parameters with the ln(MFHBF) for WUC 11000 and WUC 45000, respectively, for these aircraft combinations, are presented. In the WUC's studied, the correlations of the combined Type A and B aircraft appeared in reasonable agreement with those of the Type B aircraft. The Type A aircraft correlations were different from those of the Type B and combined Type A and B, in the degree and direction of the correlation. Since the Type L aircraft were all land-based aircraft, in general, the combination of Type A, B, and L aircraft formed the least compatible aircraft group.

TABLE 6-2. BREAKDOWN BY WUC OF MFHBF AVAILABLE FOR FIXED WING AIRCRAFT PREDICTION EQUATION DEVELOPMENT

WUC	Total of Type A MFHBF	Total of Type B MFHBF	Total of Type L MFHBF	TOTALS A+B+L	TOTALS A+B	TOTALS A+L
00000	8	19	5	32	27	13
11000	8	19	5	32	27	13
12000	8	19	5	32	27	13
13000	8	19	5	32	27	13
14000	8	19	5	32	27	13
20000	1	19	0	20	20	0
22000	3	0	5	8	3	8
23000	0	15	0	15	15	0
24000	2	0	5	7	2	7
27000	1	6	0	7	7	1
29000	8	19	5	32	27	13
41000	8	19	5	32	27	13
42000	8	19	5	32	27	13
44000	8	19	5	32	27	13
45000	8	19	5	32	27	13
46000	8	19	5	32	27	13
47000	6	19	5	30	25	11
49000	8	19	4	31	27	12
51000	8	19	5	32	27	13
56000	8	19	5	32	27	13
57000	6	18	1	25	24	7
61000	6	3	5	14	9	11
62000	3	6	5	14	9	8
63000	8	18	5	31	26	13
64000	8	14	5	27	22	13
65000	8	17	5	30	25	13
66000	5	11	4	20	16	9
67000	4	15	4	23	19	8
69000	3	2	4	9	5	7
71000	7	18	5	30	25	12
72000	8	19	5	32	27	13
73000	5	18	4	27	23	9
74000	2	15	3	20	17	5
75000	2	16	3	21	18	5
76000	4	18	3	25	22	7
77000	1	9	3	13	10	4
91000	8	19	5	32	27	13
93000	1	5	0	6	6	1
96000	4	11	5	20	15	9
97000	3	18	1	22	21	4

TABLE 6-3. CORRELATION OF ln(MFHBF) WITH FIXED WING AIRCRAFT DESIGN/PERFORMANCE PARAMETERS -- WUC 11000

AIRCRAFT CHARACTERISTICS	CORRELATION COEFFICIENTS ($\|r\| \geq .5$) A	B	A&B	A&B&L
Crew Size -- Cockpit or Total		-.741		
No. of Moveable Flt. Control Surfaces	.504	-.561		
No. of Vertical Tails	-.644			
Tail Span		-.767	-.582	
Wing Span -- Unfolded		-.793	-.549	
No. of Wing Plus Tail Folds		-.669	-.518	-.613
Max. Aircraft Length		-.824	-.637	
Wheelbase		-.641	-.552	
Fuselage Wetted Area		-.799	-.684	
Wing Area	-.654	-.823	-.772	
Total Wetted Area		-.541	-.519	
Fuselage Volume		-.787	-.601	
Aspect Ratio		-.600		
Flt. Control Surface Area		-.732	-.597	
Gun Weight		.588	.521	
No. of Guns		.662	.573	
Pressurized Fuselage Volume	-.584	-.525		
Avionics Weight Installed		-.734		
Avionics Weight Uninstalled		-.750		
Total Generator Electrical Power		-.680	-.572	
Total FCS Weight		-.807	-.529	
Kinetic Energy		-.643	-.523	-.510
Fuel Capacity Internal Wing		-.742	-.568	
Fuel Capacity Internal Fuselage		-.718		
Fuel Capacity Max. Internal		-.774		
Total Fuel Capacity		-.808	-.507	
No. of Internal Tanks		-.600		
No. of Engines		-.801	-.676	
Total Aircraft Thrust -- Military		-.755		
Max. Engine Diameter	.829			
Max. Engine Length	-.844			
Specific Fuel Consumption	-.609			
Turbine Inlet Temperature	-.514			
Empty Weight		-.853	-.748	
Flight Design Weight		-.875	-.768	
Max. Take-Off Wt. -- Cat. or Normal		-.880	-.757	
Max. Ldg. Wt. -- Arrested or Design		-.876	-.778	
Min. Time: Sea Level to 30K Feet	-.578			
Min. Combat Mission Time	.558			
Max. Combat Mission Time	.571			
Max. Speed at Sea Level				-.794
Total Fuel Capacity -- Squared		-.811		
Fuel Cap. Ext. Tanks -- Squared		-.559		

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TABLE 6-4. CORRELATION OF ln(MFHBF) WITH FIXED WING AIRCRAFT DESIGN/PERFORMANCE PARAMETERS -- WUC 45000

AIRCRAFT CHARACTERISTICS	CORRELATION COEFFICIENTS ($\lvert r \rvert \geq .5$) A	B	A&B	A&B&L
Crew Size -- Cockpit or Total	.552			
No. of Fixed Inlets		.581	.558	.585
No. of Variable Inlets		-.550	-.534	
Max. No. of External Armament Stores	.607			
Tail Span		-.600		
No. of Wing Plus Tail Folds	.607	-.745		-.559
Max. Aircraft Length		-.788	-.634	
Mean Aerodynamic Chord -- MAC		-.605	-.575	
Wheelbase		-.677		
Fuselage Wetted Area		-.662	-.545	
Wing Area		-.725	-.507	
Fuselage Volume		-.685	-.508	
Flt. Control Surface Area		-.518		
Gun Weight		.637		
No. of Guns		.706		
Total ECS Weight		-.540		
Kinetic Energy		-.524		
Fuel Capacity Internal Fuselage		-.611		
Fuel Capacity Max. Internal		-.613		
Total Fuel Capacity		-.652	-.524	
No. of Internal Tanks		-.717	-.642	-.559
No. of Engines		-.610		
Total Aircraft Thrust -- Military		-.654	-.512	
Afterburner Indicator		-.563	-.547	
Max. Engine Diameter	.650			
Max. Engine Length		-.628	-.597	
Engine Weight Installed Per Engine		-.602	-.541	-.534
No. of Fan Plus Compressor Stages		-.587		
Empty Weight		-.702	-.511	
Flight Design Weight		-.715	-.586	
Max. Take-Off Wt. -- Cat. or Normal		-.689	-.622	
Max. Ldg. Wt. -- Arrested or Design		-.681	-.532	
Max. Payload	-.534			
Bypass Ratio	.607			
Max. Wing Loading	.747			
Max. Service Ceiling -- 100 FPM		.646		
Max. Combat Mission Time	.592			
Max. Speed -- Mach No.		-.564	-.534	-.514
EW Indicator		.635		
Total Fuel Capacity -- Squared		-.640		
No. of Engine Parts		-.607	-.587	-.574

The anticipated problem with two sets of prediction equations was the lack of homogeneity within the Type A group. Few of the aircraft characteristics with intuitive appeal were strongly correlated with the MFHBF or the ln(MFHBF) of the WUC's studied. It was likely, therefore, that any Type A prediction equations using primarily intuitive variables would have poor predictive ability.

The decision was made to derive one baseline MFHBF prediction equation for each WUC using the combined data of the Type A and Type B aircraft groups, with the Type L aircraft data included for WUC's where only a limited amount of MFHBF data was available. By combining the aircraft groups, a larger number of data points would be used to develop the prediction equations and the form of the prediction model would be simplified. As the correlations of the combined Type A and Type B aircraft groups were very similar to those of the Type B aircraft, it was felt that a single prediction equation with good predictive ability could be developed.

The general approach used to develop the fixed wing aircraft prediction equations was similar to that used to develop the Type B aircraft prediction equations. Using the combination of Type A, Type B, and Type L aircraft chosen for deriving the equation, each two-digit WUC was examined with respect to use of the natural log transformation of the MFHBF (see Section 6.2). Through analysis of the correlation and regression results, a set of predictor variables for each equation, was chosen from the charateristics originally selected as candidate variables for the Type B prediction equations (see Section 6.3).

Forty baseline MFHBF prediction equations were developed for the fixed wing aircraft prediction model. Thirty-eight equations were for predicting the baseline MFHBF for two-digit WUC subsystems and one equation was for predicting the baseline MFHBF of turbojet and turbofan engines, WUC's 23000 and 27000, and is identified by WUC 20000. The remaining equation, which predicted the overall MFHBF of the aircraft, denoted WUC 00000, was developed to validate the overall MFHBF computed by combining the two-digit WUC predictions.

The statistical quality of the baseline MFHBF prediction equations, derived for the fixed wing aircraft, was generally the same as that of the prediction equations derived for Type B aircraft. In a few cases, the fixed wing aircraft prediction equation was not as good, statistically, as that previously derived for Type B aircraft. The difference was attributed to the Type B aircraft forming a more homogeneous set of data, than the combined Type A and B aircraft group. As with the Type B equations, the set of predictor variables included in the prediction equations for the engine WUC's were not as engine related as desired (see Section 6.1.2 for details).

Before finalizing the Fixed Wing Aircraft Prediction Model, some further analysis was done to refine the baseline MFHBF prediction equations. This analysis was required to reduce the number of predictor variables in the prediction equations, develop better prediction equations for certain WUC subsystems, and insure the predictive ability of the Fixed Wing Aircraft Prediction Model.

Most of the prediction equations required a reduction in the number of predictor variables, as there were too many predictor variables relative to the number of data points used to derive the equation. The guideline that the final number of predictor variables should not be more than half the number of aircraft used to derive the equation was used to determine the number of deletions required. While this reduced the value of R^2 below the goal of 0.90 in most cases, the reduction in the number of prediction variables was necessary to insure that the prediction equation was not overfitting the data; i.e., that the equation was not approaching saturation.

To make the appropriate choices for deletion, various statistical indicators were examined. Those variables shown to have the least predictive ability, as indicated by the t-statistics, for both the least squares solution and appropriate ridge solution (see Section 6.4), were omitted first. If additional deletions were required, equations were derived using various subsets of the remaining variables. The "best" reduced set of predictor variables was chosen by comparing the R^2's of the least squares solution, the R^2's of the ridge solution, the size of the ridge parameter, k, the value for the SSE, and the estimated standard deviation, $\hat{\sigma}$, relative to the number of predictor variables in the prediction equation.

As a means of improving the prediction equations, selected characteristics were studied as candidates for interaction terms. For six of the aircraft characteristics, it was found that the linear relationship between the characteristic and the MFHBF or the ln(MFHBF) was not the same for Type A and Type B aircraft. The two distinct trends, found in the bivariate plots of these six parameters, justified the formation of an interaction term which could account for this categorical difference in the data (see Section 5.5 for details).

The use of the interaction terms was restricted to those prediction equations where a substantial improvement in the statistical quality of the equations was realized. In developing a prediction equation which would account for the categorical difference in parameter values, at least two additional predictor variables were required in the equation; namely, the interaction term and the Type A or B indicator variable. To compensate for the added variables and avoid overfitting the equation to the data, other aircraft parameters, previously chosen as predictor variables, had to be excluded from the equation.

Table 6-5 shows the development of the baseline MFHBF prediction equation for the Oxygen Systems (WUC 47000) through the refinement phase of the analysis. Similar refinement occurred for each prediction equation developed for the model. Equation 1 was the prediction equation developed through the analysis of the natural log transformation and selection of predictor variables, as discussed in Sections 6.2 and 6.3, respectively. While the number of predictor variables was less than half the number of data points used to develop the equation, the t-statistics indicated that the Max. Thrust to Max. Take-Off Weight had little predictive ability in this equation. Therefore, the Max. Thrust to Max. Take-Off Weight was omitted from the set of predictor variables and Equation 2 was derived. As indicated by the statistics associated with Equations 1 and 2, presented at the bottom of Table 6-5, the quality of the equation was not significantly changed by the deletion of the Max. Thrust to Max. Take-Off Weight.

As Equation 2 included two aircraft parameters for which interaction terms had been formed, Equation 3 was derived to determine if the prediction

TABLE 6-5. DEVELOPMENT OF FIXED WING AIRCRAFT BASELINE MFHBF PREDICTION EQUATION FOR THE OXYGEN SYSTEMS (WUC 47000)

$$\ln(\text{MFHBF}) = \text{Constant} + \sum b_i X_i$$

Aircraft Characteristics X_i	Coefficients b_i EQ. 1	EQ. 2	EQ. 3	EQ. 4
Crew Size -- Cockpit or Total	-.09600	-.10680	-.15047	-.08284
Pres. Fuselage Volume	-.00074	-.00078	-.00085	-.00076
Max. Serv. Ceiling	.01128	.01155	-	-
Min. Combat Mission Time	-.00046	-.00045	.01085	.00831
Total ECS Weight	-.00002	-.00002	-.00023	-
Tot. Gen. Elec. Power	.00001	.00002	-.00003	-.00004
Max. Combat Radius	.17469	-.00019	-	-
Empty Weight	-.00014	.11359	-.11056	-.08576
Max. Speed -- Mach No.	.09842	-.25861	-.10790	-
Max. Thrust to Max.T.O. Wt.	-.28894	-	-	-
(Min. Combat Mission Time) x (Type A or B)	-	-	-.32091	-.51469
Type A or B	-	-	-1.08384	-.76606
(Max. Speed -- Mach No.) x (Type A or B)	-	-	.16300	-
Constant	4.40373	4.37120	6.43032	6.39195
No. of Aircraft	25	25	25	25
No. of Predictor Variables	10	9	10	7
k	.0337	.0287	.0100	.0125
R^2 -- Least Squares	.783	.782	.856	.839
R^2 -- Ridge	.754	.758	.823	.802
SSE	1.59064	1.56433	1.14352	1.28053
$\hat{\sigma}$	.33708	.32294	.29658	.28290

equation for WUC 47000 could be further improved. The interaction terms, (Min. Combat Mission Time) x (Type A or B) and (Max. Speed -- Mach No.) x (Type A or B), along with their common indicator variable, Type A or B, were added as predictor variables. To evaluate the impact of the interaction terms, the number of predictor variables had to remain close to the number previously used. Therefore, the Max. Service Ceiling and the Max. Combat Radius, the statistically least important variables in Equation 2, were omitted. As shown by the decrease in the value of k and increase in the R^2's, the set of predictor variables used to form Equation 3 were less multicollinear and formed an equation which better fit the historical data.

An examination of the t-statistics for Equation 3 showed that the Total ECS Weight, the Max. Speed -- Mach No., and the (Max. Speed -- Mach No.) x (Type A or B) were not significantly contributing to the predictive ability of the equation. To further simplify the prediction equation, these variables were omitted, and Equation 4 was derived. While the fourth equation's fit to the data was somewhat lessened, the substantial decrease in the number of predictor variables was more significant than the small decrease in the R^2's. Thus, Equation 4 was chosen as the final baseline MFHBF prediction equation for WUC 47000.

Prior to validating the refined prediction equations' predictive ability, those aircraft characteristics of the Design/Performance Data Base chosen as predictor variables required examination. The values of most of the characteristics of notional aircraft, such as the Landing Sink Speed, were expected to remain within the range of the historical values (see Figure 6-1). For other parameters, such as the Rate of Climb at Sea Level, the historical range, as indicated by NAVAIR, was not necessarily representative of the notional range of values (see Figure 6-2). If the notional range of values was expected to be within the historical range, for all predictor variables of a given baseline MFHBF prediction equation, no problem of extrapolation was anticipated, and the equation was expected to have good predictive ability. When notional parameter values outside the range of the historical values were likely, those equations which included these characteristics would possibly have difficulty predicting a reasonable value for the MFHBF.

Anticipating possible problems predicting with some of the equations, alternate equations were considered. For some WUC's, equally good prediction

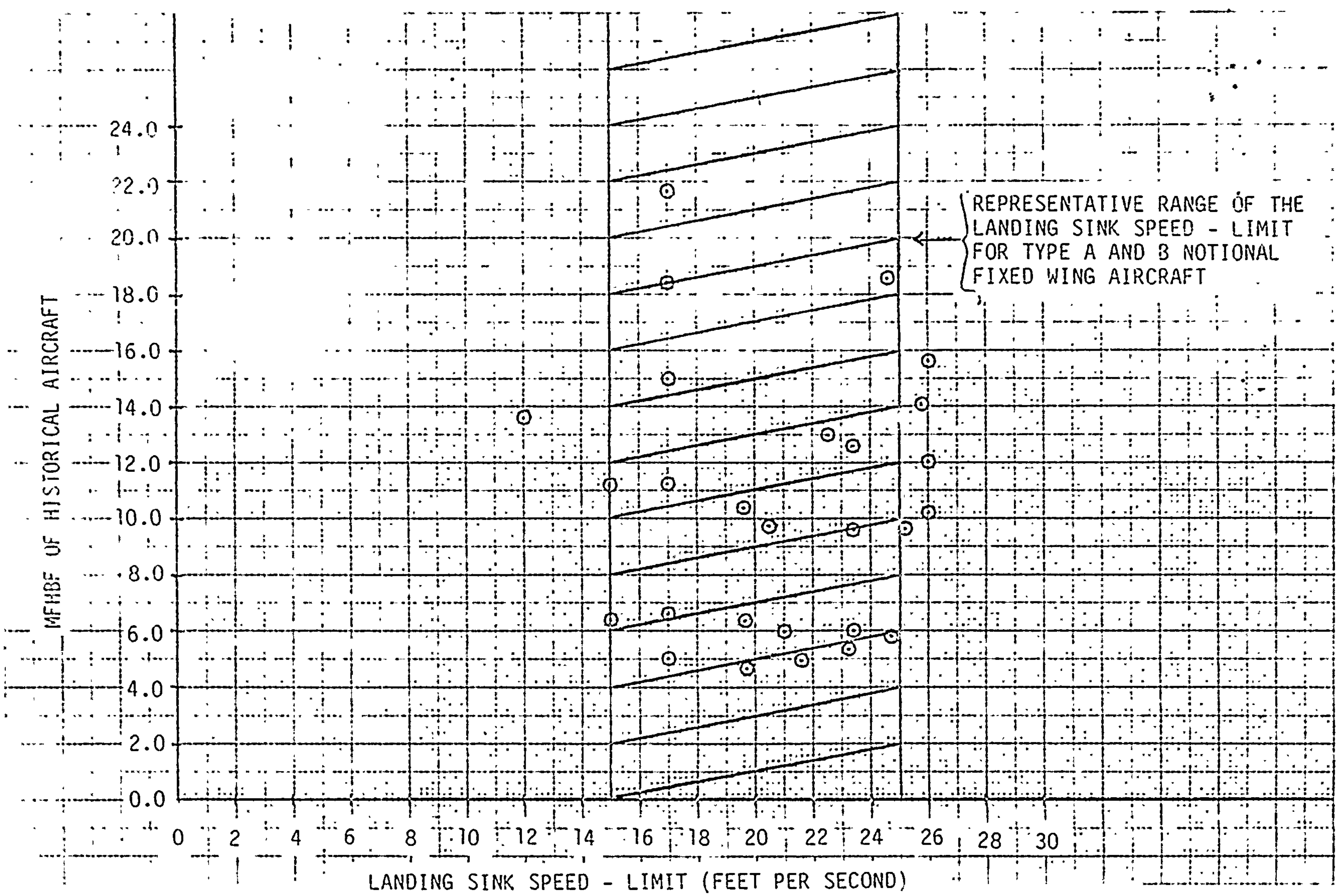

Figure 6-1. Airframe MFHBF vs Landing Sink Speed With Representative Range of Notional Fixed Wing Aircraft

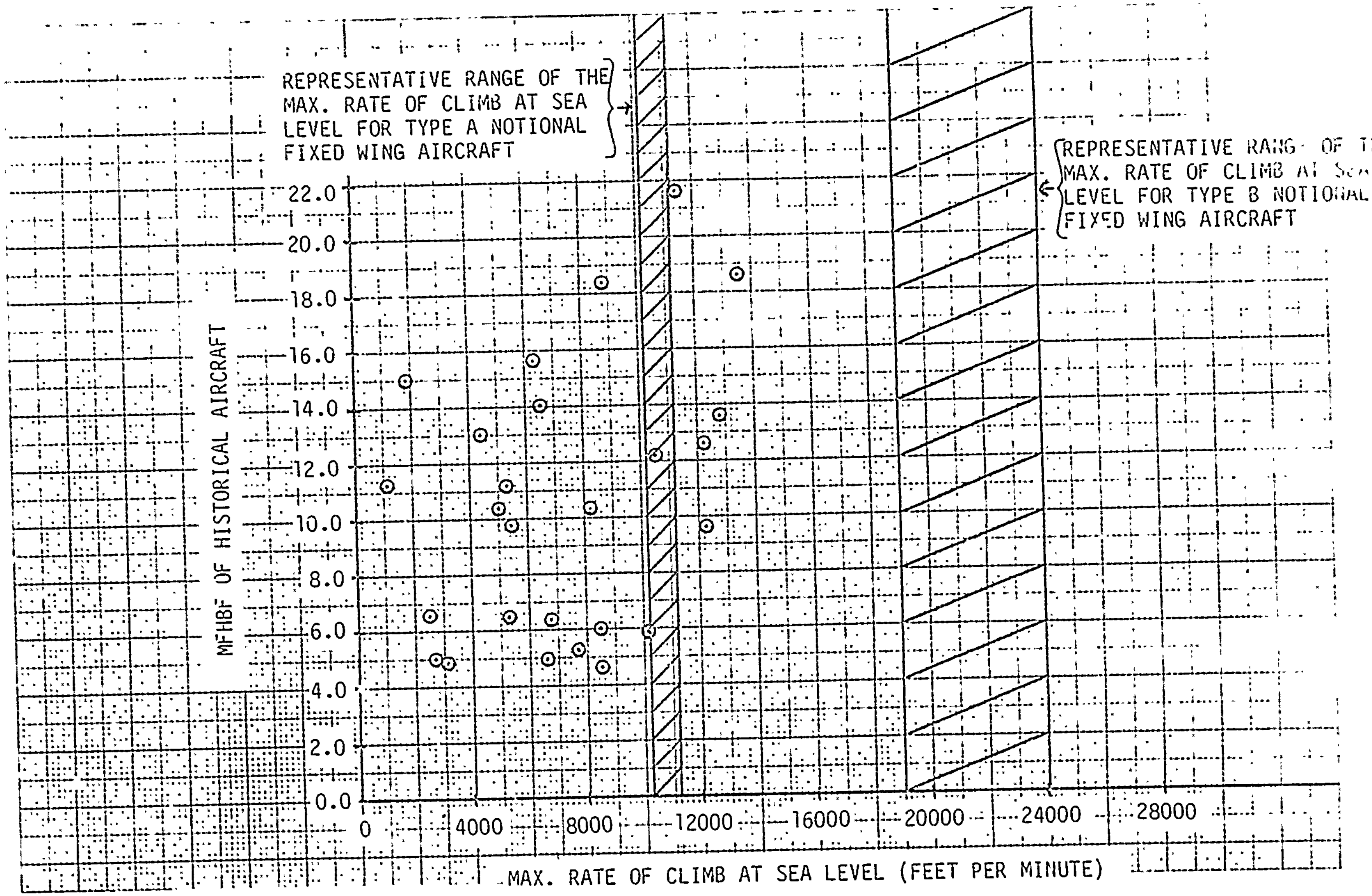

Figure 6-2. Airframe MFHBF vs Maximum Rate of Climb at Sea Level, With Representative Range of Notional Fixed Wing Aircraft

equations involving interaction terms had been derived. While other equations had been preferred, these equations were seen as alternate equations, should extrapolation prove to be a problem. In other cases, the aircraft characteristics, which would involve extrapolation, were found to be highly correlated with other aircraft characteristics, which were expected to remain within the historical ranges of values. By substituting predictor variables, it was felt that a reasonable alternate equation could be derived. Until the impact of any extrapolation was revealed during validation (see Section 7.2), no substitutions were made.

6.1.2 Formulation of Engine Prediction Equations. The procedure followed to develop the baseline MFHBF prediction equations for the engine WUC's differed from that used to develop the remaining equations of the fixed wing aircraft model. Due to the approach taken to developing the engine prediction equations, and the importance of the MFHBF of the engines to the overall reliability of the aircraft, WUC's 22000, 23000, and 27000 were given particular attention.

It was decided that the baseline MFHBF prediction equations for WUC 23000 (Turbojet Engines) and WUC 27000 (Turbofan Engines) would be derived using all aircraft with turbojet and turbofan engines, respectively. The Type A aircraft group included too few historical aircraft with turbojet or turbofan engines to develop separate engine prediction equations for Type A aircraft only.

When equations for the engine WUC's were first examined, data for only the 19 Type B aircraft were available. A single equation for predicting the MFHBF of both turbojet and turbofan engines was developed using the available data. The equation for turbofan and turbojet engines, denoted WUC 20000, was used to obtain an overview of the predictive ability of the engine related characteristics included in the Design/Performance Data Base. Separate equations would be developed when the data base was expanded to include the remaining aircraft. As all the historical Type B aircraft had turbojet or turbofan engines, an equation for WUC 22000 was not derived at that time.

For engineering and design reasons, the MFHBF for the engine WUC's were predicted on a per engine basis, instead of on an aircraft basis. The historical values included in the MFHBF Data Base were, therefore, the MFHBF per engine for each aircraft. The prediction equation for WUC 29000 (Power Plant Installation) was also derived to predict the MFHBF on a per engine basis.

The results of the correlation analysis and stepwise regression analysis for WUC 20000 and the associated candidate predictor variables were unexpected. Few of the engine related parameters were shown to be good predictors of the MFHBF for the turbojet and turbofan engines. The better parameters, statistically, for predicting the MFHBF of the turbojet and turbofan engines were either more general aircraft characteristic or non-engine related parameters.

After analyzing many sets of possible variable combinations, a prediction equation for WUC 20000 using Type B aircraft data was derived. This equation was considered less than adequate based on the choice of predictor variables. Further examination of the data was postponed until the remaining data was available.

Prior to the development of separate prediction equations for WUC 23000 and WUC 27000, an adjustment in the WUC designations for historical MFHBF values was made. The F-14A, A-7A, B, C, and E, which have turbofan engines, report the appropriate subsystem failures against WUC 23000, in accordance with the WUC Manuals. For the purpose of the study, it was felt that development of engine prediction equations by type of engine was more meaningful. Thus, the historical MFHBF data for the F-14A, A-7A, B, C, and E were used to develop the prediction equation for WUC 27000, and not for WUC 23000.

Upon completion of the data base to include all 32 historical fixed wing aircraft, the engine data was re-examined. The historical MFHBF for WUC 23000 and WUC 27000 included all Type A and Type B aircraft with turbojet and turbofan engines, respectively. The historical MFHBF for WUC 22000 included all Type A and Type L (land-based aircraft) with turboshaft engines. The Type L aircraft were included due to the limited number of Type A aircraft with turboshaft engines.

The initial results of the analysis for the three WUC's were much the same as those obtained with Type B aircraft. The engine related characteristics of the Design/Performance Data Base were not the best parameters, statistically, for predicting engine reliability of historical aircraft. The few engine characteristics with reasonably good predictive ability were not consistently important predictors for all three types of engines. As before, more general design and performance parameters appeared to be better predictors of the MFHBF of the engine WUC's.

In an attempt to develop engine equations with more intuitive appeal, six more engine characteristics were added to the Design/Performance Data Base. A complete correlation analysis was done for each engine WUC. Table 6-6 summarizes the correlations found between the engine related parameters of the data base and the MFHBF of the engine WUC's. As indicated by the size and inconsistency of the correlation coefficients across WUC's, few of these variables seemed to be potentially good predictors of the MFHBF for the engines. The additional engine characteristics did not appear any better or more consistent in their predictive ability than the original engine parameters.

While sometimes related, the correlation coefficients alone did not indicate which engine parameters were the best variables for the prediction equations. Most of the engine characteristics having the strongest correlation with the MFHBF of a particular engine WUC were themselves strongly correlated. Therefore, if one engine parameter was used as a predictor variable, adding the others did little to enhance the quality of the prediction equation. Also, when used in combination with other parameters, the relative importance of each parameter to the predictive ability of the equation would frequently shift.

As the prediction equations derived for WUC 23000 and WUC 27000 were not totally satisfactory from an intuitive viewpoint, a combined turbojet/turbofan engine prediction equation, denoted by WUC 20000, was derived. With the combined data from the two sets of aircraft, many of the engine related parameters were found to be reasonably good predictors of the MFHBF.

TABLE C-6. CORRELATION OF ENGINE RELATED PARAMETERS WITH HISTORICAL MFHBF OF ENGINE WUC SUBSYSTEMS FOR FIXED WING AIRCRAFT

Engine Related Parameters	Correlation Coefficient			
	22000	23000	27000	20000
Max. Thrust Per Engine	.450	-.054	-.791	-.261
Max. Engine Diameter	-.745	.088	.160	.303
Max. Engine Length	.425	-.125	-.245	-.194
Engine Weight Installed Per Engine	-.160	-.004	-.701	-.265
No. of Fan Plus Compressor Stages	.000	.106	.569	.303
No. of Turbine Stages	.000	.104	.773	.486
Max. Compression Ratio	.412	-.080	.625	.440
Specific Fuel Consumption	-.405	-.131	-.717	-.525
Turbine Inlet Temperature	.529	-.029	-.142	.225
Bypass Ratio	N/A	.000	-.142	.596
Max. Thrust to Installed Engine Weight	.473	-.068	.138	.111
Max.Thrust or SHP to Engine Weight Uninstalled	.469	-.044	.229	.234
*Specific Thrust or SHP	.421	-.011	-.408	-.309
Max. Airflow	.047	.014	-.365	.115
*Max. Pressure Ratio	.000	-.167	.716	.442
Fuel to Air Ratio	.425	.047	-.479	.086
*Engine Weight Uninstalled Per Engine	-.053	.026	-.840	-.288

*Added to the Design/Performance Data Base

The parameters finally chosen for the engine prediction equations of the fixed wing aircraft model were somewhat a compromise. Those engine related parameters displaying consistently good predictive ability were combined with the more general aircraft characteristics showing the strongest predictive ability. Through this approach, neither the engineering credibility nor the statistical quality of the equations was sacrificed.

6.1.3 Formulation of Rotary Wing Aircraft Model. The circumstances surrounding the formulation of the Rotary Wing Aircraft Prediction Model greatly simplified the development of the model. As the Fixed Wing Aircraft Prediction Model had previously been derived, the methodology used in model development had been established. Since the eleven historical rotary wing aircraft chosen for model development formed a smaller and more homogeneous group of aircraft than the fixed wing aircraft, there was no reason to consider development of more than one set of prediction equations for predicting the baseline MFHBF.

The general procedure followed in developing the rotary wing aircraft prediction equations was the same as that used to develop the fixed wing aircraft prediction equations. The selection of candidate variables for use in each two-digit WUC equation was made as outlined in Section 6.3. Particular attention was given to the rotary wing analogues to the fixed wing aircraft characteristics found to be important predictor variables. Developing equations to predict the natural log of the MFHBF versus the MFHBF was considered, based on trends found in the bivariate plots of the MFHBF and the design/performance parameters (see Section 6.2). The natural log transformation was again found to improve the equations' fit to the data for many two-digit WUC subsystems.

As an example of the development process, Table 6-7 shows the development of the baseline MFHBF prediction equation for the Hydraulic and Pneumatic Power (WUC 47000) to its final form. Several of the aircraft characteristics selected as possible predictor variables were the rotary wing equivalent of

TABLE 6-7. DEVELOPMENT OF ROTARY WING AIRCRAFT BASELINE MFHBF PREDICTION EQUATION FOR THE HYDRAULIC AND PNEUMATIC POWER (WUC 45000)

$$Y = \text{Constant} + \sum b_i X_i$$

Aircraft Characteristics X_i	Coefficients b_i Eq. 1 ($Y=\overline{MFHBF}$)	Eq. 2 ($Y=\ln(\overline{MFHBF})$)	Eq. 3 ($Y=\overline{MFHBF}$)
Vert. Rate of Climb at Sea Level -- Mil.	.00091	.00004	.01264
No. of Main Rotor Blades	30.13800	.38092	16.62264
Main Rotor Disc Area	-.05517	-.00141	-.03029
Total A/C SHP -- Mil. or Int. Power	.00941	.00032	.00310
Max. Disc Loading	1.92650	.11776	2.35658
Tail Pylon Fold	-4.89751	.62887	-
Eng. Wt. Installed per Engine	.00040	-.00023	-
Constant	3.17561	3.18910	-1.11821
No. of Aircraft	11	11	11
No. of Predictor Variables	7	7	5
K	.0000	.0000	.0175
R^2 -- Least Squares	.986	.956	.986
R^2 -- Ridge	.986	.956	.950
SSE	55.3547	.0971	193.89028
$\hat{\sigma}$	4.29553	.18000	6.22720

the fixed wing aircraft characteristics chosen as final predictor variables. For example, the Total Aircraft SHP -- Mil. or Int. Power and the Max. Disc Loading could be equated to the Total Aircraft Thrust -- Military and the Max. Wing Loading included in the fixed wing aircraft prediction equation for WUC 45000.

Using the characteristics given in Table 6-7, Equation 1 was developed using step-up regression. The order in which the characteristics are listed reflects the order of selection by the step-up procedure. Since a ridge solution was not available using step-up regression, the statistics of the equation give the least squares value for the ridge parameter, k, and the coefficient of determination, R^2. The equation formed by these design/performance parameters was statistically a good fit to the data, as reflected by the value of R^2.

Equation 2 was derived to determine if a better fit to the data could be obtained by developing an equation to predict the ln(MFHBF), instead of the MFHBF. The bivariate plots of the ln(MFHBF) versus most of the aircraft characteristics revealed an improved linear association over the bivariate plots involving the MFHBF. The ln(MFHBF) version of the equation, however, did not prove to be as good, statistically, as Equation 1. While the sum of squares for error, SSE, and the estimated standard deviation, $\hat{\sigma}$, could not be compared due to the transformation used in Equation 2, the R^2's indicated that Equation 1 provided the better fit.

Having decided on the MFHBF version for the prediction equation, the results of the step-up regression for Equation 1 were further analyzed. The Tail Pylon Fold and the Engine Weight Installed per Engine, the last two characteristics chosen as predictor variables, were found to contribute little to the predictive ability of the equation. The addition of these characteristics neither increased the value of R^2, nor substantially decreased SSE. This was easily explained since the Tail Pylon Fold and the Engine Weight Installed per Engine were highly correlated with the Number of Main Rotor Blades and the Max. Disc Loading, respectively. Once the Number of Main Rotor Blades and the Max. Disc Loading were included in the equation, the use of the other two characteristics as predictor variables was mathematically redundant.

Thus, Equation 3 was derived using only the first five characteristics ... Equation 1. As shown by the statistics for this equation, the R^2 for the least squares solution was unchanged, indicating an equally good fit to the data with fewer variables. By eliminating two strongly correlated variables, the R^2 of the ridge solution remained close in size to the R^2 of the least squares solution.

In general, the quality of the Baseline MFHBF Prediction Equations derived for the rotary wing aircraft was statistically good. This was attributed to the homogeneous group of aircraft used to develop the equations.

As with the fixed wing aircraft, some further analysis was required prior to finalizing the Rotary Wing Aircraft Prediction Model. Some of the prediction equations required a reduction in the number of predictor variables included in the equation to avoid overfitting the data. The guideline that the final number of predictor variables should not be more than half the number of aircraft used to derive the equation was generally used to determine the number of deletions required. A few prediction equations, however, were allowed an additional predictor variable when the deletion of the variable resulted in a significant decrease in R^2. Because the smaller number of rotary wing aircraft meant fewer predictor variables per equation than for the fixed wing aircraft, to have required the deletion of a parameter with reasonable predictive ability, could have significantly reduced the equation's predictive ability with notional aircraft.

Any prediction equations not having the statistical quality desired were sufficiently improved with the substitution of parameters already contained in the data base. Thus, no additions were made to the Design/Performance Data Base. Interaction terms were not considered for the rotary wing equations as distinct trends were not apparent using data from only eleven aircraft.

Prior to validating the model, those equations involving parameters for which the notional aircraft values were likely to lie outside the historical range of values were identified. The use of notional parameter values outside the historical range means extrapolating with the equations involving these parameters. This would possibly lead to difficulty in predicting a reasonable value for the MFHBF of the associated two-digit WUC subsystems.

Anticipating some problems in predicting for notional aircraft, alternate characteristics were found. In all cases, the aircraft characteristics which might involve extrapolation were found to be highly correlated with other characteristics which were expected to have notional aircraft values within the range of historical values. With the substitution of these characteristics, a reasonable alternate equation could be derived, should extrapolation prove to be a problem during validation (see Section 7.2).

6.2 Transformations of the Data. The use of transformations was studied many times in the development of the Baseline MFHBF Prediction Models. Transformations on both the MFHBF and selected design/performance parameters were investigated as a means of obtaining better equations for predicting the baseline MFHBF at a two-digit WUC level. Consideration of transformed variables were restricted to situations where there were strong indications that a transformation was appropriate.

It became apparent, in examining bivariate plots that for many two-digit WUC's, use of a transformation on the MFHBF should be considered. The bivariate plots of the MFHBF versus various design/performance characteristics of the aircraft revealed a "L-shaped" curve in the plotted points. The fact that the "L-shaped" curve was found using the same MFHBF data with many different aircraft characteristics was an indication that the transformation should be performed on the MFHBF.

The square root transformation and the natural log transformation of the MFHBF were both examined in an attempt to improve the linearity of the data. While some improvement was shown with the square root of the MFHBF, the bivariate plots of the data still showed some curvature. A much stronger linear trend in the data was seen when the natural log of the MFHBF, ln(MFHBF), was plotted against the various aircraft characteristics. This improvement was also indicated by an increase in the absolute value of the correlation coefficients. A comparison of Figures 6-3 and 6-4, showing the MFHBF of WUC 14000 for fixed wing aircraft versus the Wing Sweep and the ln(MFHBF) versus the Wing Sweep, respectively, reflects the type of improv...

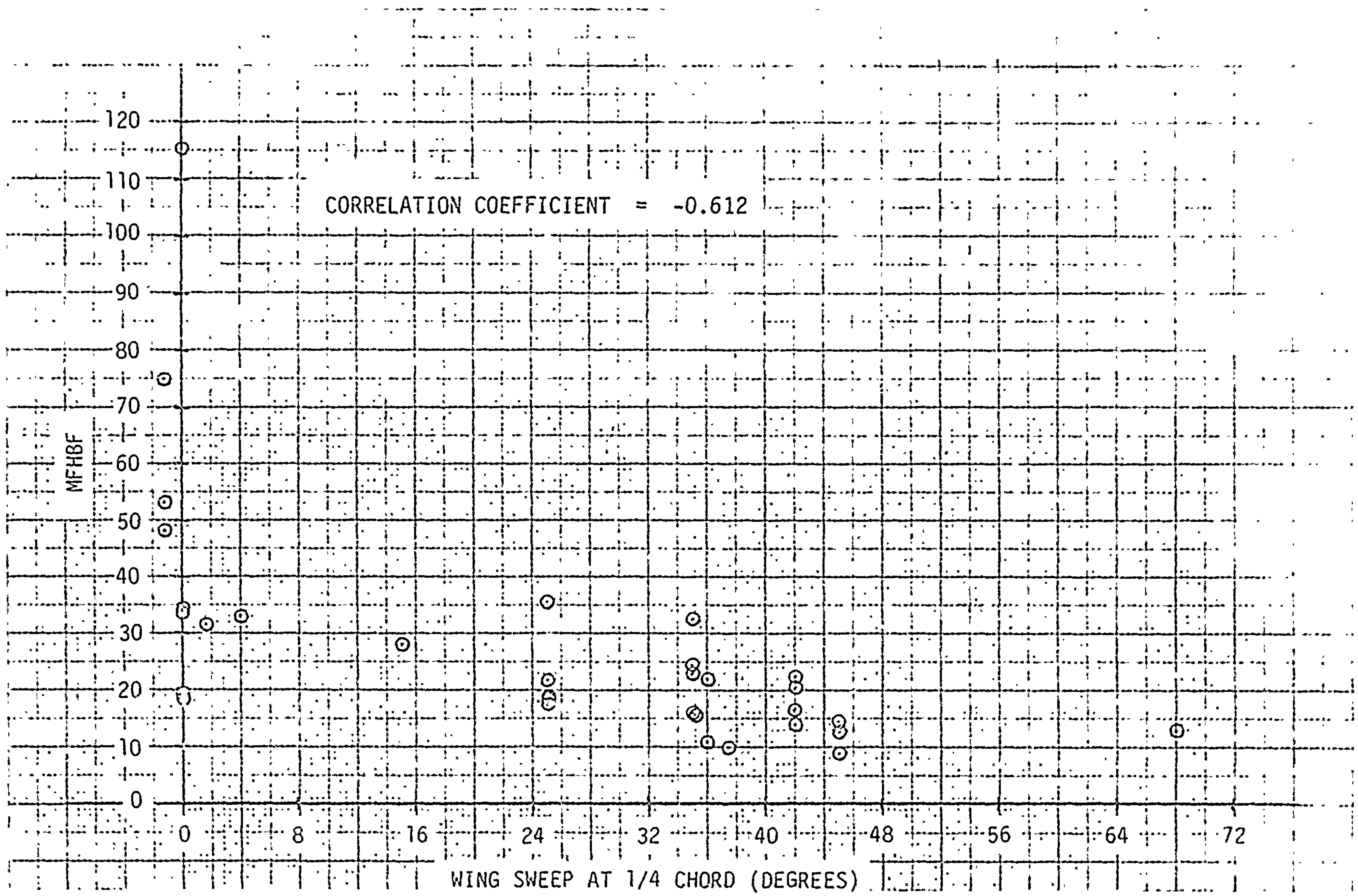

Figure 6-3. MFHBF -- WUC 14000 vs Wing Sweep For Fixed Wing Aircraft

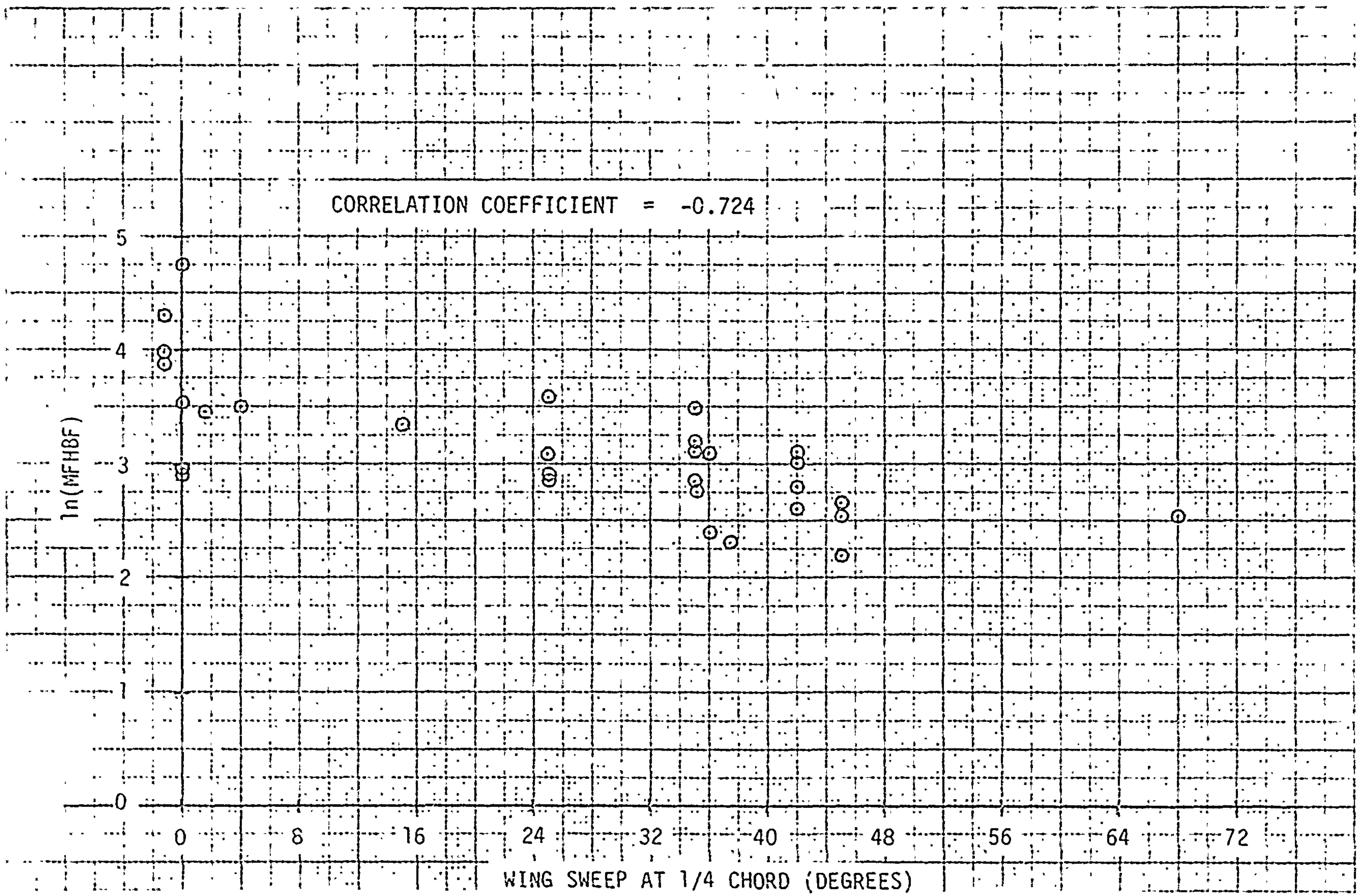

Figure 6-4. ln(MFHBF) -- WUC 14000 vs Wing Sweep For Fixed Wing Aircraft

linear relationship often seen when the natural log transformation was applied to the MFHBF.

It was suspected, therefore, that a substantially better fit to the data could be obtained by developing an equation to predict the ln(MFHBF) instead of the MFHBF, for many two-digit WUC's. The choice of which dependent variable, the MFHBF or the ln(MFHBF), was to be used in each prediction equation was made based on which version of the prediction equation provided the best fit to the data, as measured by the coefficient of determination, R^2. The ln(MFHBF) was chosen for those WUC's where the increase in R^2 was substantial; otherwise, the MFHBF remained as the dependent variable of the prediction equation.

The possible use of transformed design/performance characteristics was studied in only a few cases. Few of the bivariate plots revealed a trend in the data which suggested the use of a transformation. In most of the bivariate plots, either the aircraft characteristics showed a strong linear association with the MFHBF or the ln(MFHBF) for various two-digit WUC's, or they appeared unrelated to the dependent variable.

The squared value of two design/performance parameters for fixed wing aircraft were used in the development of prediction equations for Type B fixed wing aircraft. A "U-shaped" trend was found in the bivariate plots of the Total Fuel Capacity and the Fuel Capacity of External Tanks with the MFHBF and ln(MFHBF) for Type B aircraft. By squaring these parameters, their linear association with the dependent variables was improved and they were found to be good predictor variables for certain WUC's. When the remaining fixed wing aircraft were included, the squared terms were no longer good predictors for any two-digit WUC's, and, therefore, were omitted from the final prediction equations of the fixed wing aircraft prediction model.

6.3 Predictor Variable Selection. Three different techniques were jointly used in selection of the design/performance parameters to be considered for use in the baseline MFHBF prediction equations. The selection process was an iterative procedure which occurred many times during development of both the fixed wing and rotary wing aircraft prediction

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models. While each prediction equation was derived in a slightly different manner, the general routine followed in selecting predictive variables was basically the same.

6.3.1 Initial Selection. Engineering judgement was used to determine the design/performance parameters which would initially be considered as possible predictor variables for each of the two-digit WUC equations. With the assistance of design and systems engineers, one of four levels of priority was assigned to each characteristic of the Design/Performance Data Base. The levels of priority were assigned to reflect the degree of influence each aircraft characteristic was felt to have in predicting the MFHBF of each two-digit WUC subsystem. By initiating the selection process using engineering expertise, the aircraft parameters which should have no connection with a specific WUC were eliminated, and those aircraft parameters with intuitive appeal were given a higher priority.

Two forms of correlation analysis were also involved in the selection of aircraft characteristics. First, the correlation between pairs of design/performance parameters was derived. By examining the correlation between the aircraft characteristics, "statistically equivalent" parameters were determined, as well as those parameters for which the degree of linear association was insignificant (see Section 5.4 for details). Table 6-8 and Table 6-9 present the correlation coefficients for a selected group of fixed wing and rotary wing aircraft characteristics, respectively. The direction and degree of linear association between the aircraft characteristics was crucial in determining which parameters were used as predictor variables in the equations. In Figure 6-5, the bivariate plot of the Wing Span Folded versus the Flight Controls Surface Area for the fixed wing aircraft data values, is shown. In Table 6-8, this pair of independent variables is shown to have a correlation of 0.926.

The correlation coefficients between the aircraft characteristics and the MFHBF for a given two-digit WUC were also derived. These correlations often provide an indication of which parameters may have good predictive ability for the WUC. Figure 6-6 graphically displays the association between the MFHBF of the Flight Controls and the Flight Control Surface Area of the fixed wing

TABLE 6-8. CORRELATION MATRIX OF SELECTED FIXED WING AIRCRAFT CHARACTERISTICS

	Correlation Coefficient							
	No. of Variable Inlets	Wing Span-- Folded	Fuselage Volume	Wing Area	Flight Control Surface Area	Empty Weight	Max. Service Ceiling	Max Speed -- Mach No.
No. of Variable Inlets	1.0	-.131	-.104	-.074	-.181	.027	.125	.922
Wing Span -- Folded		1.0	.984	.952	.926	.902	-.586	-.254
Fuselage Volume			1.0	.962	.921	.930	-.755	-.231
Wing Area				1.0	.959	.952	-.641	-.248
Flight Control Surface Area					1.0	.929	-.547	-.315
Empty Weight						1.0	-.580	-.224
Max. Service Ceiling							1.0	.406
Max. Speed -- Mach No.								1.0

TABLE 6-9. CORRELATION MATRIX OF SELECTED ROTARY WING AIRCRAFT CHARACTERISTICS

	Correlation Coefficient							
	Empty Weight	Aircraft Length-- Operating	Total A/C SHP -- Mil. or Int. Pwr.	Main Rotor Gear Ratio	Main Rotor Blade Area	Avionics Weight Installed	Max. Disc. Loading	Max. Speed at Sea Level
Empty Weight	1.0	.725	.923	-.389	.813	-.182	.777	.770
Aircraft Length -- Operating		1.0	.534	-.391	.299	-.432	.193	.494
Tot. Aircraft SHP-- Mil. or Int. Pwr.			1.0	-.417	.841	-.218	.795	.877
Main Rotor Gear Ratio				1.0	.014	-.125	.690	.641
Main Rotor Blade Area					1.0	.015	.838	.606
Avionics Weight Installed						1.0	-.024	-.477
Max. Disc Loading							1.0	.722
Max. Speed at Sea Level								1.0

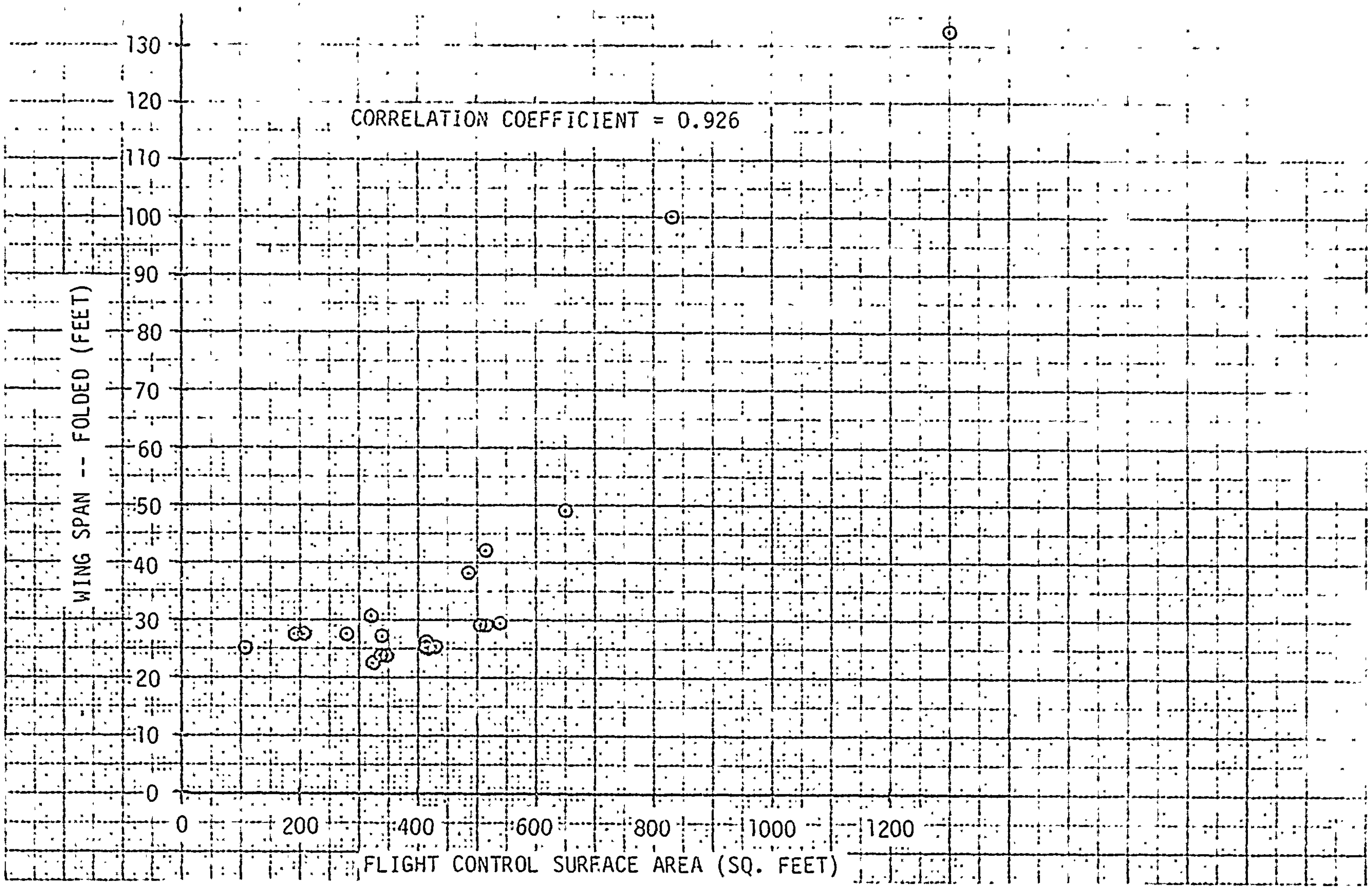


Figure 6-5. Wing Span -- Folded vs Flight Control Surface Area For Fixed Wing Aircraft

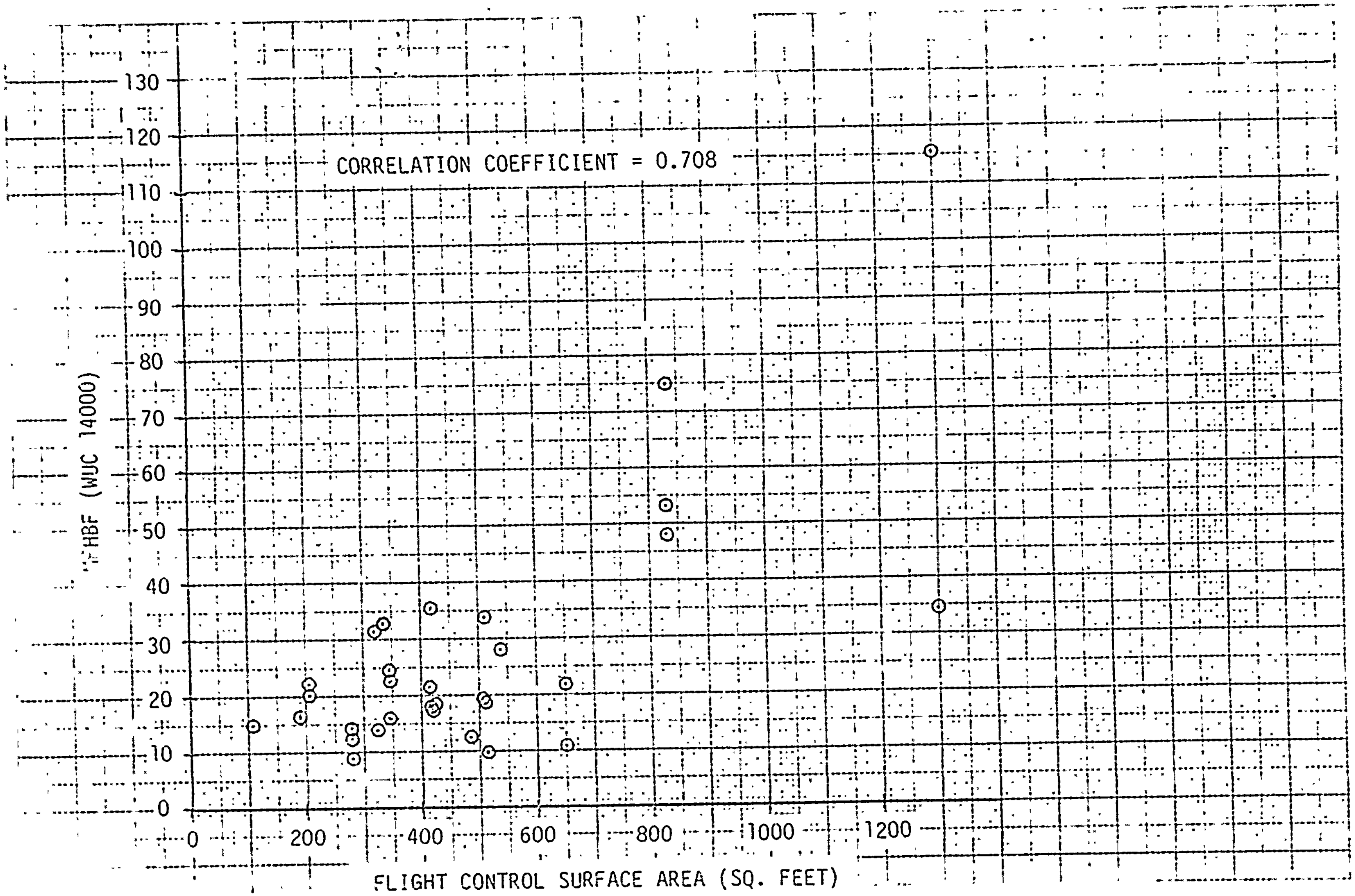


Figure 6-6. MFHBF -- WUC 14000 vs Flight Control Surface Area for Fixed Wing Aircraft

aircraft. With an associated correlation of 0.705, it appears that the Flight Control Surface Area is potentially a good predictor of the MFHBF for the Flight Controls (WUC 14000) for fixed wing aircraft.

In most cases the number of variables to be considered for use in the baseline MFHBF prediction equation for a two-digit WUC was greater than the equation could handle mathematically. The number of predictor variables which can be included in the prediction equation is limited by the number of aircraft with MFHBF values available for the WUC subsystem. A forward selection regression procedure was used to eliminate those variables with poor predictive ability from further consideration (see Section 5.3 for details).

The forward selection, or step-up, procedure provided valuable information concerning the final selection of predictor variables for the equation. The presence of multicollinearities became apparent, based on the choice of variables made for the equation by the step-up regression procedure, and the effect each variable had on the size and sign of other coefficients, as each variable was added to the equation. The homogeneity of the data and the adequacy of the engineering choices for predictor variables were indicated by the number of variables required to achieve various values of R^2 for each equation.

6.3.2 Refinement. As the prediction equations were further refined, the use of engineering judgement, correlation analysis, and step-up regression were again employed. The role each of these techniques played in the subsequent selection of predictor variables differed from their role in the initial selection process.

Correlation analysis was used to analyze step-up regression results. Examination of pairwise correlations alone did not detect all multicollinearities in the data. However, examination of the correlation coefficients, along with the order in which the aircraft parameters were selected, would often indicate whether the use of all or some of the highly correlated parameters had a positive effect on the quality of a prediction equation.

If two aircraft parameters were highly correlated, one parameter was included early in the forward selection process, and the other parameter was among the last chosen, the use of both aircraft characteristics was mathematically redundant. If a redundancy was implied by using both parameters as predictor variables, and if engineering/design considerations confirmed the relationship, one of the parameters was eliminated. The inclusion of both as predictor variables would have increased the degree of multicollinearity in the data used to develop the prediction equation.

The choice of which aircraft characteristic to eliminate was based on engineering judgement. The characteristic with more intuitive appeal for the WUC subsystem being considered remained in the equation. For example, as shown in Table 6-8, the number of Variable Inlets and the Max. Speed -- Mach No. for fixed wing aircraft have a correlation of 0.922. Statistically, these characteristics are considered to be equivalent. While the Number of Variable Inlets might be the more appropriate of the two as a predictor variable of the MFBHF for WUC 14000 (Flight Controls), the Max. Speed -- Mach No. might be more appropriate for WUC 29000 (Power Plant Installation).

Engineering judgement was also involved in considering the addition of parameters to the Design/Performance Data Base. The initial step-up regression results indicated the general adequacy of the data base parameters as predictor variables. For some WUC's, the characteristics available in the data base did not produce a statistically good equation for predicting the MFHBF. Other aircraft parameters considered potentially important for design and engineering reasons were added to the Design/Performance Data Base for use with these WUC's.

The step-up regression procedure was used to analyze the impact of the addition and deletion of parameters from consideration as possible predictor variables for a two-digit WUC prediction equation. The regression results revealed which aircraft characteristics were consistently good predictors of the MFHBF of a given two-digit WUC. Many parameters were found to have good predictive ability only when combined with certain other characteristics to form the prediction equation. These results also indicated whether the parameters added or deleted from consideration were statistically good choices.

Through the forward selection procedure, an upper limit on the number of aircraft parameters required to form a statistically good prediction equation for each WUC was established. This maximum number was determined by examining the results as each aircraft parameter was chosen as a predictor variable for the equation. The point at which the increase in R^2 and the decrease in SSE was minimal with the addition of another variable was the determining factor in establishing an upper limit on the number of predictor variables needed in the equation.

6.4 Estimation of Prediction Equation Coefficients. Estimates of the coefficients for the baseline MFHBF prediction equations and equations derived in the final stages of model development were primarily determined by the presence of multicollinear data. Certain guidelines were developed so that consistency would be established in the choice of estimates used.

If the Variance Inflation Factors (VIF's) did not indicate the presence of multicollinearities in the data used for development of the equation, the least squares estimates for the coefficients were used. When multicollinear data was present, ridge estimates were used to offset the effect of the multicollinearity and provide more stable estimates.

To arrive at a set of ridge estimates, a choice of the parameter k had to be made. To insure the proper choice was made, both the k-value determined by the rule associated with the maximum VIF and k-value computed from the least squares solution were examined (see Section 5.6 for details).

In the development of some of the prediction equations, the computed k-value was considerably larger than the value derived by the VIF rule. This immediately indicated some lack of homogeneity in the data. Therefore, the computed k-value was the clear choice to ensure that the coefficients used were sufficiently stable. Hopefully, the size of the computed k-value was not so large as to cause a drastic decrease in R^2 or increase in SSE.

In most cases, the computed k-value was only slightly larger than that derived by the VIF rule. While the difference between the two values was insignificant, the computed k-value was again used to avoid an unanticipated sensitivity to the use of extrapolated data; i.e., the more stable the coefficient, the better the chance for a "good" prediction with extrapolated data.

On occasion, the computed k-value was found to be smaller than required to meet the guidelines of having all VIF values less than or equal to 10. This was primarily due to the small number of predictor variables in the equation relative to the number of aircraft being used to derive their associated coefficients. In such situations, the k-value determined by the maximum VIF rule was used. The computed k-value would not have sufficiently reduced the effects of the multicollinear data; namely, coefficient estimates with inflated variance values.

7. MODEL VALIDATION

In the model validation phase, the adequacy of the models, the sensitivity of the models to the data bases, and the accuracy of the final baseline MFHBF prediction equations were examined. Because of the large number of equations in the Baseline Reliability Prediction Models and the variety of validation techniques used, certain analyses were limited to only a selected set of prediction equations. The prediction equations for WUC's 11000 (Airframe), 13000 (Landing Gear), 41000 (Air Conditioning/Pressurization/Ice Control), and 63000 (UHF Communications) were examined for both fixed wing and rotary wing aircraft. The other fixed wing aircraft equation examined was for WUC 27000 (Turbofan Engines), while the additional rotary wing aircraft equation was for WUC 22000 (Turboshaft Engines).

These ten prediction equations were selected in order that (1) the different data backgrounds involved in equation development were represented, and (2) the WUC's provided a wide range of functional areas of the aircraft. For instance, with the fixed wing aircraft, the prediction equation for WUC 27000 was derived using only seven aircraft data points and the prediction equation for WUC 63000 was derived using both land and carrier-based aircraft. While the failure rate reported for WUC 11000 and WUC 13000 would be major contributors to the overall MFHBF of fixed wing and rotary wing aircraft, the failure rate reported for WUC 63000 would have less impact.

7.1 <u>Technical Approach</u>. Several procedures were used in validating the Baseline Reliability Prediction Models. Those techniques which validated the prediction equations themselves were restricted to the five fixed wing and five rotary wing equations identified above, while those techniques which validated overall models involved all equations.

One of the techniques for validating the prediction equations consisted of comparing the data base or "historical" values for the ln(MFHBF) and/or the MFHBF against the predicted values. As mentioned in Section 5.2, the sum of squares for error provided an overall measure of the differences between the historical or true values and predicted values. However, this did not rule out the possibility of an extreme difference between the historical and predicted values for a given aircraft. The purpose of examining the two sets of values was to determine if any such extreme differences existed.

Examination of the standardized residuals is a technique frequently used for both verifying the distributional assumptions made in the analysis and determining the adequacy of the prediction equations. For the set of equations described in Section 5.1,

$$Y_i = \beta_0 + \sum_{j=1}^{p} \beta_j X_{ij} + \varepsilon_i, \text{ for } i=1, \ldots n,$$

the following assumptions are generally made in regression analysis:

1. The Y_i's used in the analysis constitutes a random sample.
2. The error terms, ε_i's, are statistically independent.
3. The ε_i's are normally distributed.
4. The ε_i's have means of zero.
5. The ε_i's have constant variance, σ^2.

Given these assumptions, the standardized residuals, $e_i = \dfrac{Y_i - \hat{Y}_i}{\sqrt{Var(Y_i - \hat{Y}_i)}}$,

are normally distributed with zero mean and unit variance. Using plots of the cumulative frequency versus the standardized residuals, i.e., "normal plots", and the predicted values derived from each equation versus the standardized residuals, the assumptions of normality and homoscedasticity (constant variance), respectively, were assessed.

In the normal plots, the standardized residuals were graphed on a normal probability distribution grid. The plotted points approximated a straight line, if the normality assumption was satisfied. Any indication of nonnormality could have been due to the need for a transformation on the historical values or a lack of fit to the data.

If the assumption of constant variance held, the variability in the plots of the predicted values against the standardized residuals was fairly uniform. That is, a uniform band could have been drawn such that the plotted points would lie within the region. If a systematic change in the plotted points was detected, then the prediction equation was statistically inadequate. This inadequacy could have been handled with an appropriate transformation on the historical values for the MFHBF.

Data-splitting was not used in validation due to the number of aircraft used in development of the model. Such techniques are traditionally reserved for large data sets. Instead, the technique of omitting individual aircraft from the data base and deriving adjusted coefficients for the prediction equations was employed to check the sensitivity of the coefficients.

Ideally, an adjusted equation would have been obtained for the omission of each aircraft used in development of the baseline prediction equation. Even in restricting the use of this procedure to the ten prediction equations of interest, a total of 172 sets of adjusted coefficients would have been derived. Therefore, only four aircraft omissions for each of the ten two-digit WUC prediction equations were considered. In each case, the aircraft associated with the maximum MFHBF, minimum MFHBF, maximum residual value, and minimum residual value were omitted from the data base, one at a time, and adjusted coefficients derived. These four data values are usually the most influential in determining the estimated coefficient values.

No statistical procedure exists for analyzing the adjusted coefficients. Whether or not a prediction equation was acceptable, based on the results of the "leave-one-out" technique, was primarily a matter of judgement. While some shift in coefficients was expected, if the equation was stable, no radical change in the coefficients, R^2, SSE, or the ridge parameter, k, should have occurred. A large change implied the prediction equation was sensitive to the MFHBF and parameter values of the historical aircraft.

To validate the overall models, the MFHBF for each fixed wing and rotary wing aircraft used in model development were predicted at the two-digit WUC subsystem level, using the equations of the Baseline Reliability Prediction Models. The predicted MFHBF values for each two-digit WUC were then compared to their corresponding historical values. The predicted MFHBF values for the aircraft, obtained from the equation for the overall reliability and by combining the predicted values for the two-digit WUC subsystems, were compared to their respective historical MFHBF values for the aircraft. Through this procedure, the relative accuracy of the prediction equations for historical aircraft, and the adequacy of the models in detecting changes in configuration were examined.

Since the baseline MFHBF prediction equations will be used with notional aircraft design/performance parameter values, whether or not the model had reasonably good extrapolation properties was a crucial indication of the model's predictive ability. To examine the quality of the baseline MFHBF predictions using extrapolated data, the prediction equations were provided to NAVAIR. NAVAIR used these equations to predict the baseline MFHBF values for notional aircraft designs of the Sea Based Air Master Study (SBAMS) Aircraft Alternatives Definition Task. NAVAIR applied the prediction model to 40 of the candidate SBAMS fixed wing aircraft designs and to four of the candidate SBAMS rotary wing aircraft designs. Approximations were used for those design/performance parameter values not readily available in the format required for use of the equations. A comparison was performed, within NAVAIR, of the models' predicted baseline MFHBF for each two-digit WUC subsystem against the fleet 3-M MFHBF values initially used as a NAVAIR Baseline for the SBAMS aircraft estimates.

7.2 Results. Through results of the validation phase, the predictive ability of the Baseline Reliability Prediction Models was determined. The predictive ability was measured by the adequacy, sensitivity, and accuracy with which the fixed wing and rotary wing prediction models predicted the reliability of historical and notional aircraft, and the individual prediction equations predicted at the two-digit WUC subsystem level. Since the ten prediction equations chosen for validation involved a wide cross-section of two-digit WUC subsystems and combination of aircraft, their results were considered representative of all prediction equations.

Examination of the predicted versus historical values for the ten prediction equations revealed no statistically significant differences in the two sets of values. Graphs of the values predicted from the equations ver .

The historical values used to derive the equations are shown in Figures 7-1 and 7-2. For those equations predicting the ln(MFHBF), a graph involving the ln(MFHBF) values, as well as a graph of the MFHBF values, are presented. In each graph, both the individual points and the overall scatter were found to reflect normal variation in the values.

While the difference between the historical and predicted values appeared to be extreme for selected aircraft in the graphs of WUC 41000 and WUC 63000 for fixed wing aircraft, only two aircraft had a difference greater than two standard deviations in each case. Under the assumption of normality, this was not statistically improbable, given the number of aircraft used to derive the equations.

As indicated by the normal plots given in Figures 7-3 and 7-4, the normality assumption appeared to be well substantiated in all but two cases. Except in normal plots of WUC 41000 and WUC 63000 for rotary wing aircraft, the plotted points tended to form a straight line. Thus, the form of the associated prediction equations was considered to be statistically adequate; i.e., additional predictor variables were not needed in the prediction equations.

The points in the normal plots of WUC 41000 and WUC 63000 for rotary wing aircraft more closely approximated two lines instead of one. Since less than 20 aircraft were used to derive these equations, it was difficult to determine if the data was, in fact, not normal. As a lack of normality would have implied the need for additional variables in the prediction equation, the two prediction equations were left in their existing form. The addition of predictor variables, causing the equation to overfit the data, would have had a more negative effect on the predictive ability of the equation than a possible lack of normality in the data.

The plots of the predicted value against the standardized residuals did not reflect any significant departure from the assumption of constant variance. As shown by the graphs in Figures 7-5 and 7-6, no systematic change

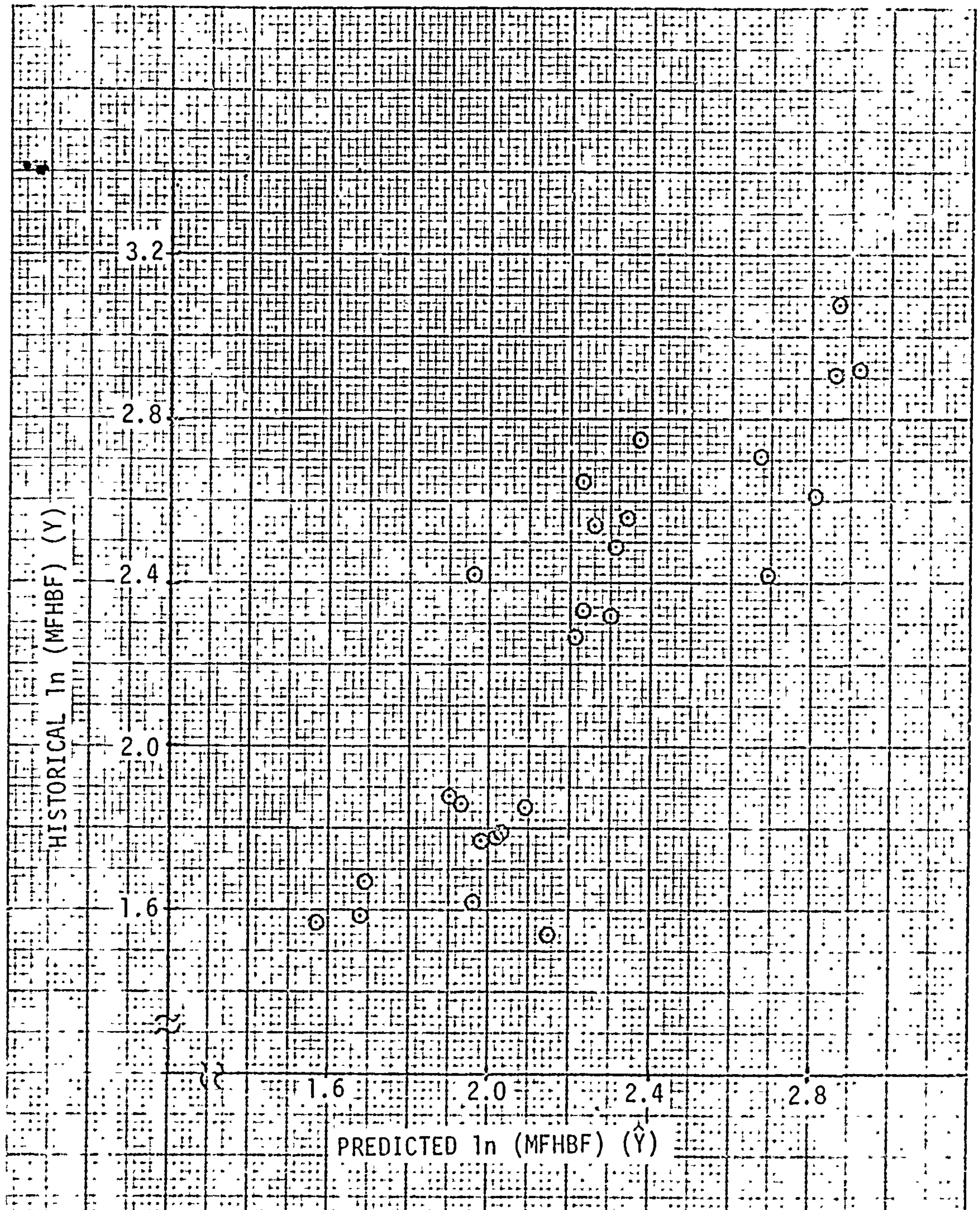


Figure 7-1. Predicted ln(MFHBF) vs. Historical ln(MFHBF)
For Fixed Wing Aircraft -- WUC 11000

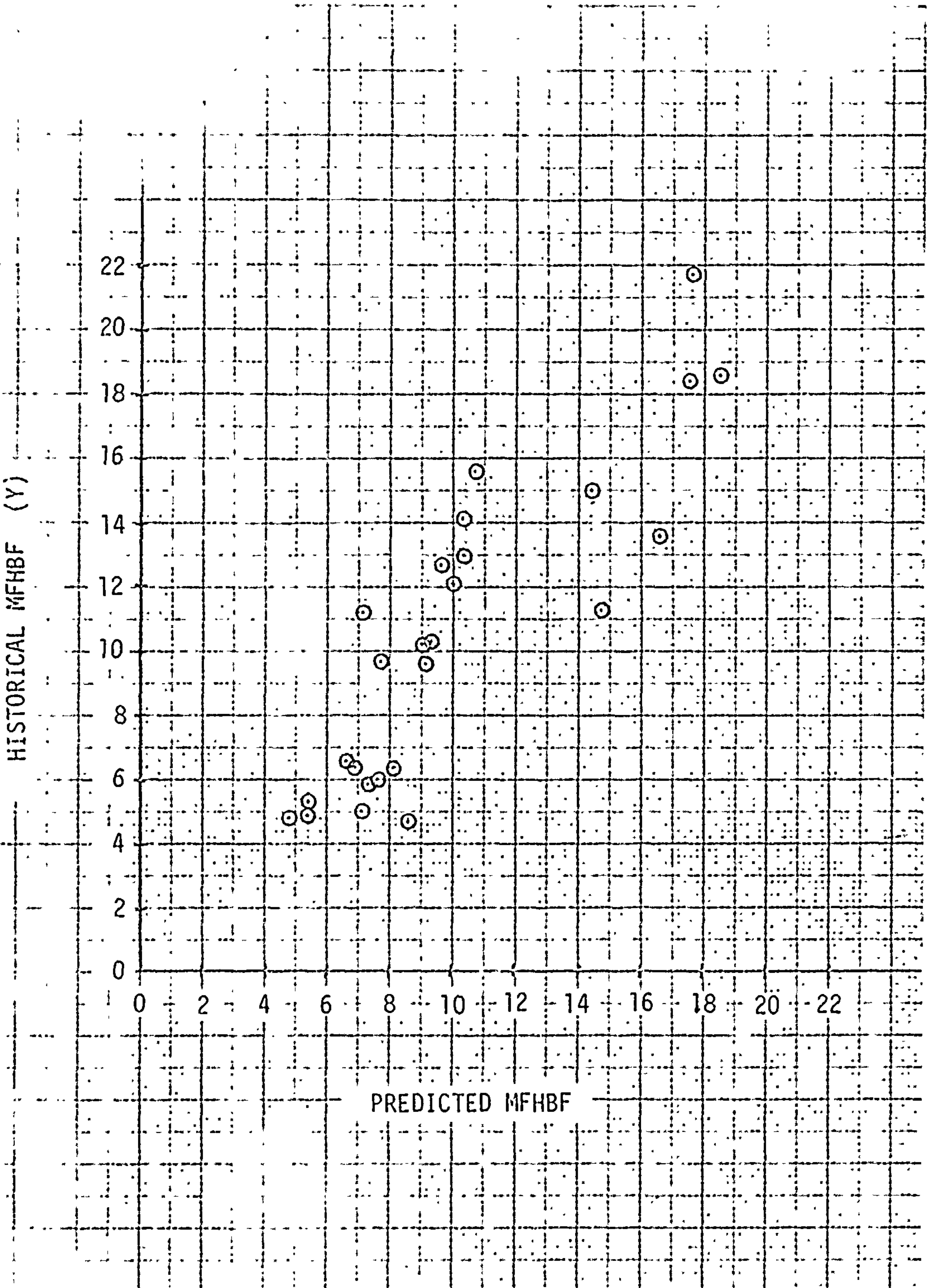


Figure 7-1 (Cont.). Predicted MFHBF vs Historical MFHBF
For Fixed Wing Aircraft -- WUC 11000

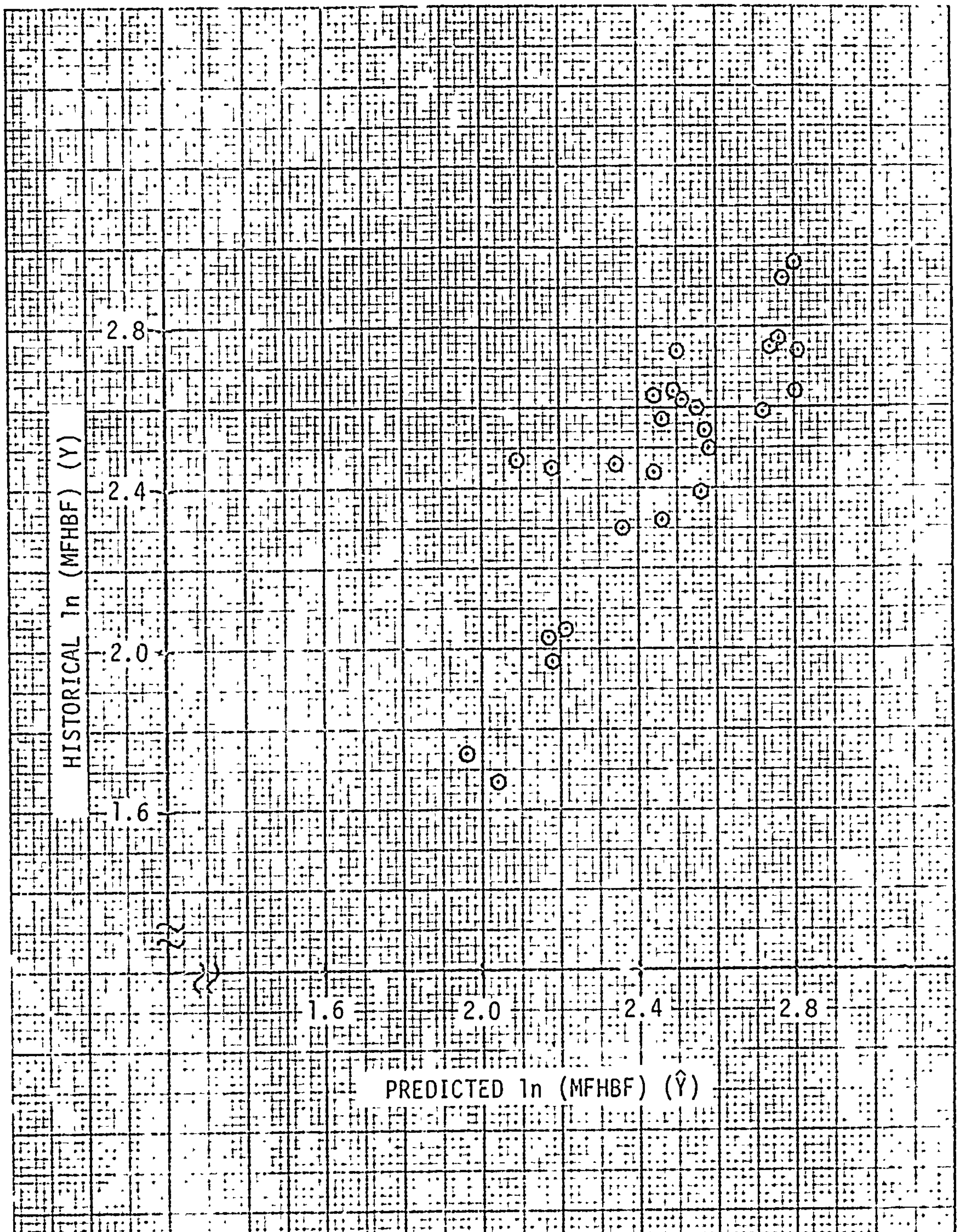


Figure 7-1 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Fixed Wing Aircraft -- WUC 13000

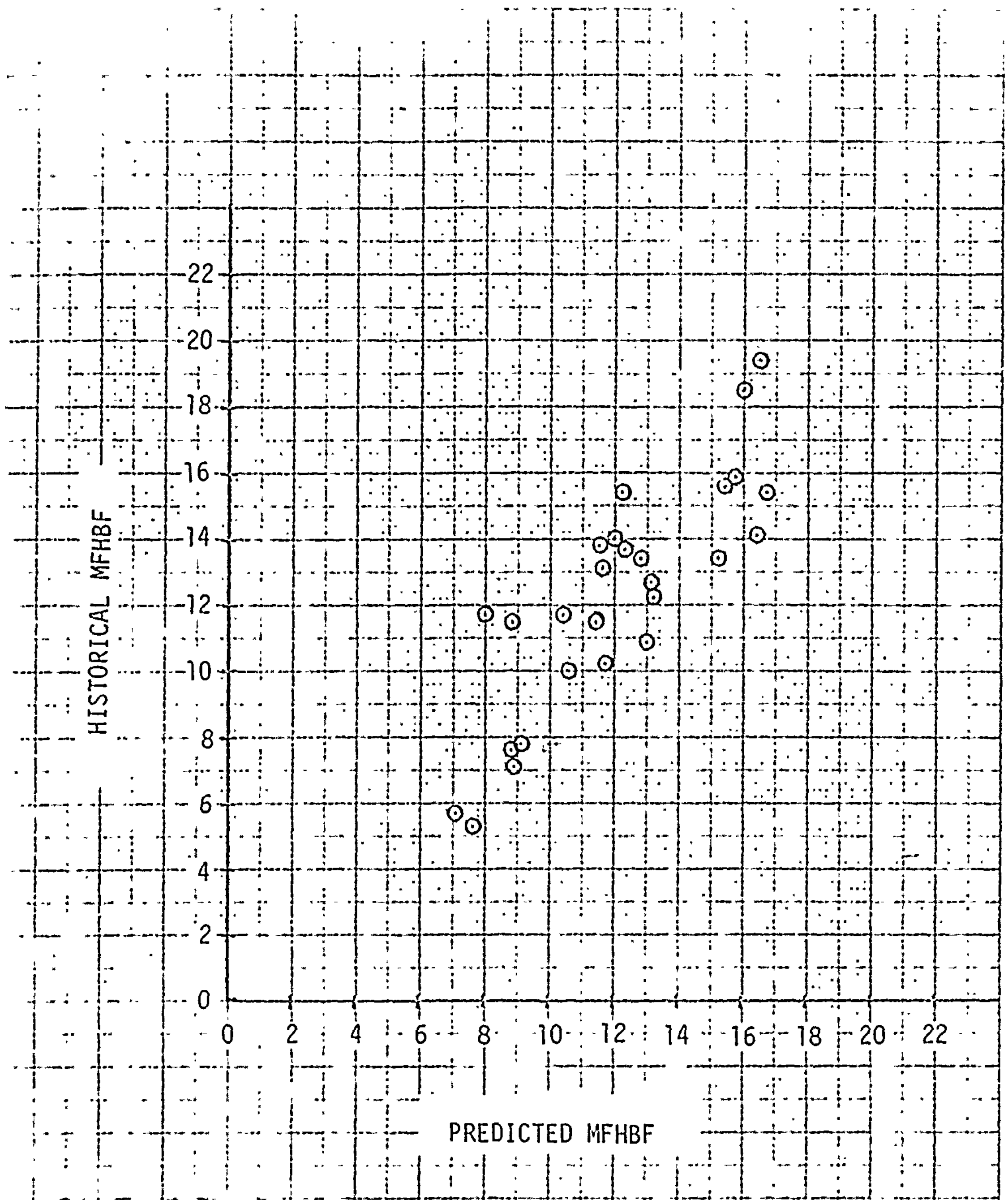


Figure 7-1 (Cont.). Predicted MFHBF vs Historical MFHBF
For Fixed Wing Aircraft -- WUC 13000

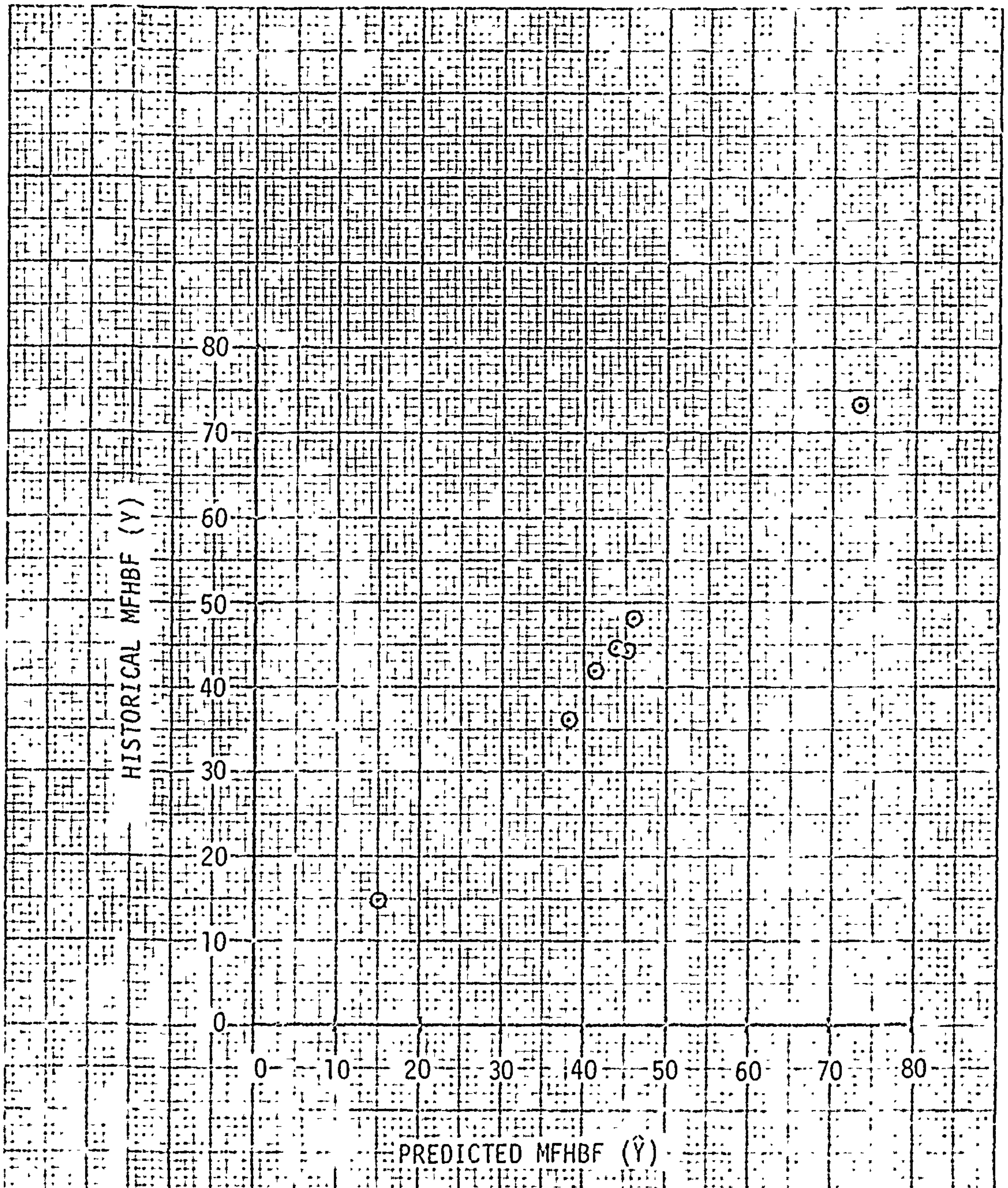


Figure 7-1 (Cont.). Predicted MFHBF vs Historical MFHBF For Fixed Wing Aircraft -- WUC 27000

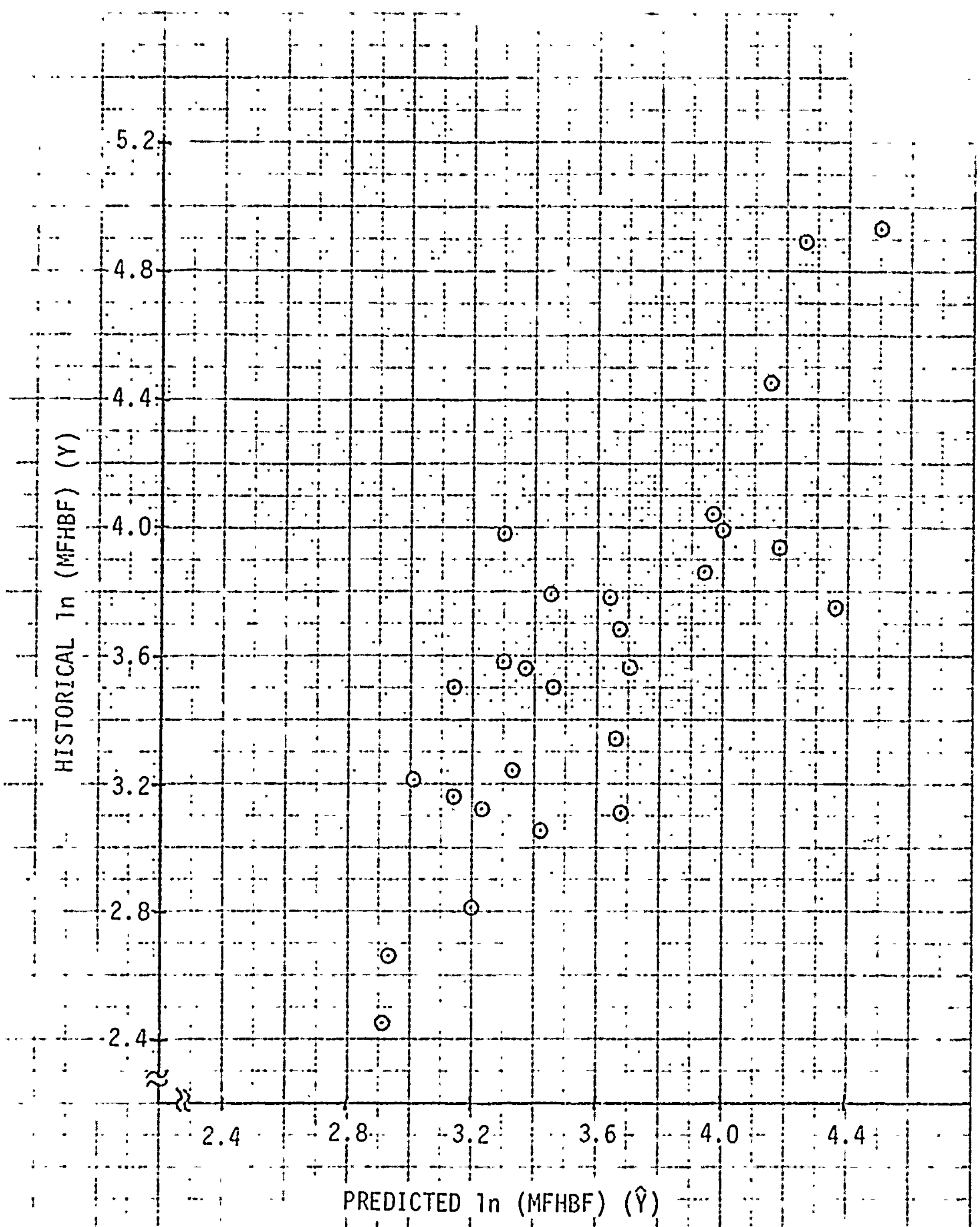


Figure 7-1 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Fixed Wing Aircraft -- WUC 41000

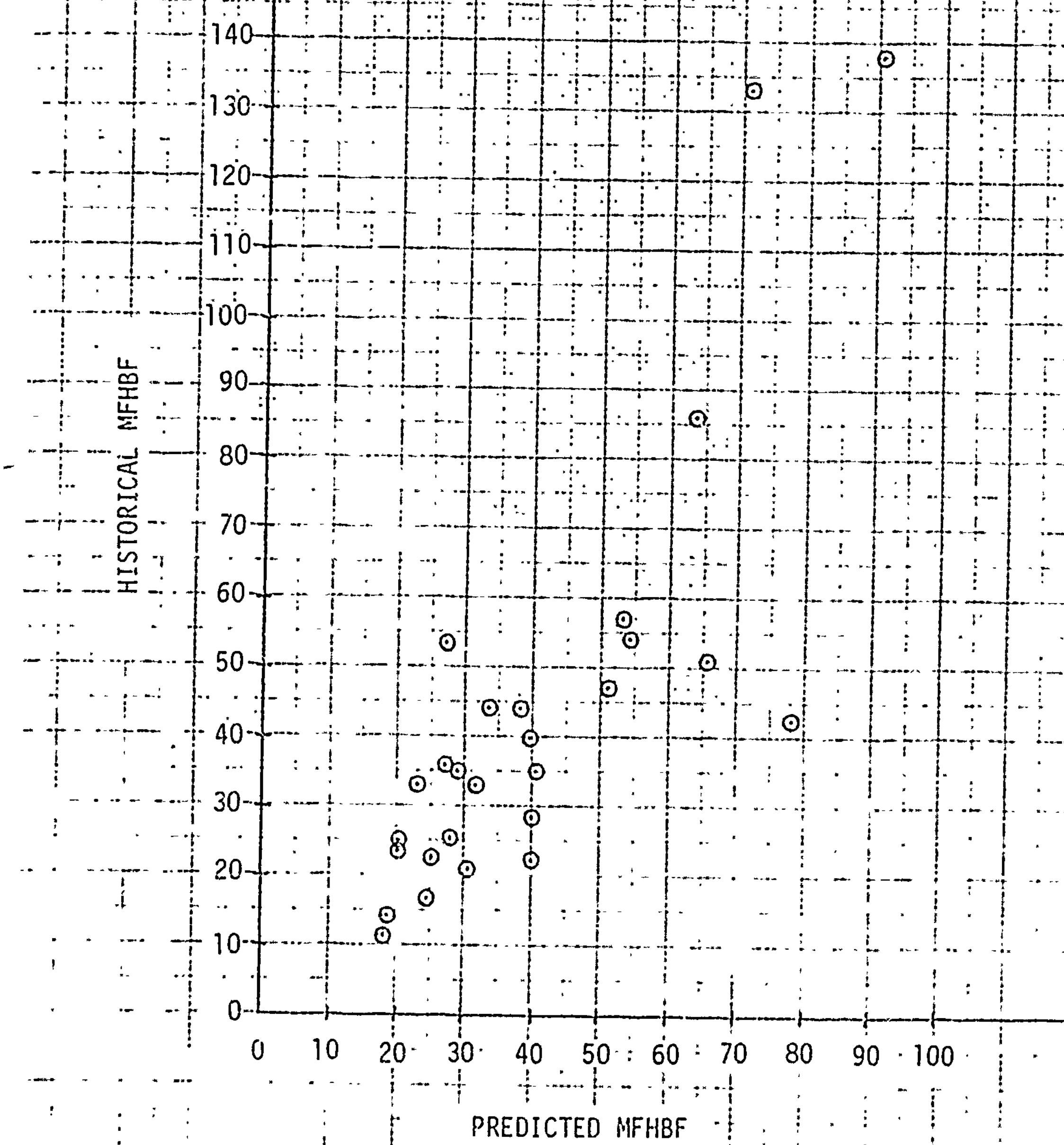


Figure 7-1 (Cont.). Predicted MFHBF vs Historical MFHBF For Fixed Wing Aircraft -- WUC 41000

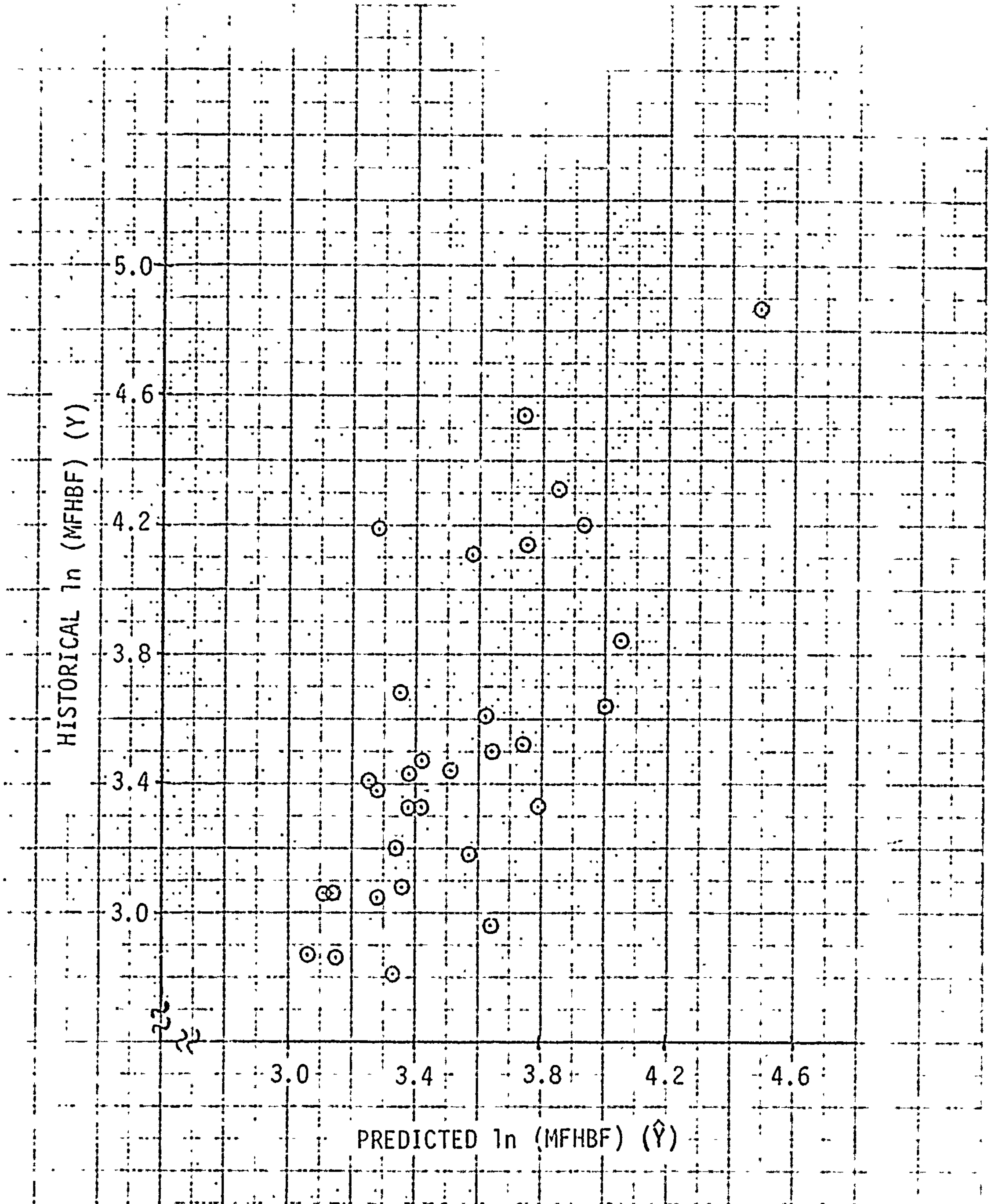


Figure 7-1 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Fixed Wing Aircraft -- WUC 63000

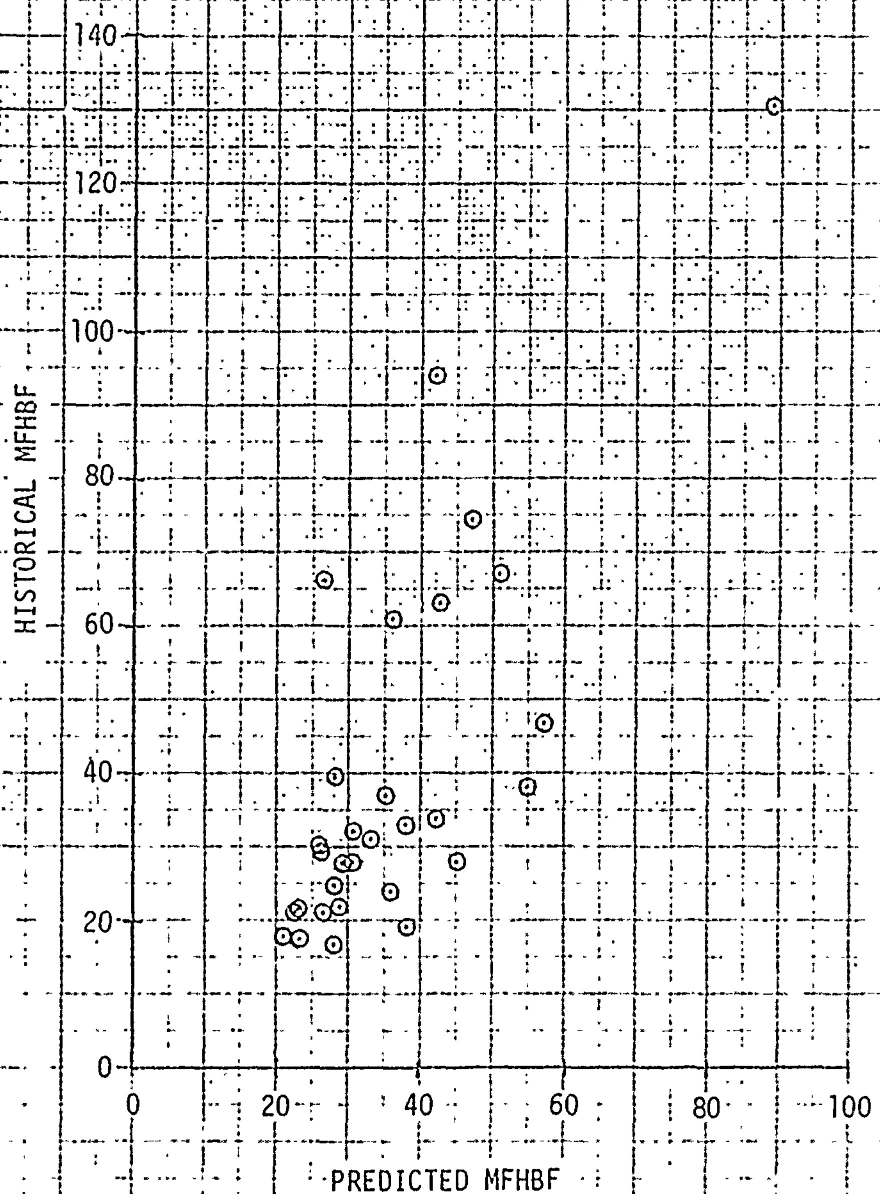


Figure 7-1 (Cont.). Predicted MFHBF vs Historical MFHBF For Fixed Wing Aircraft -- WUC 63000

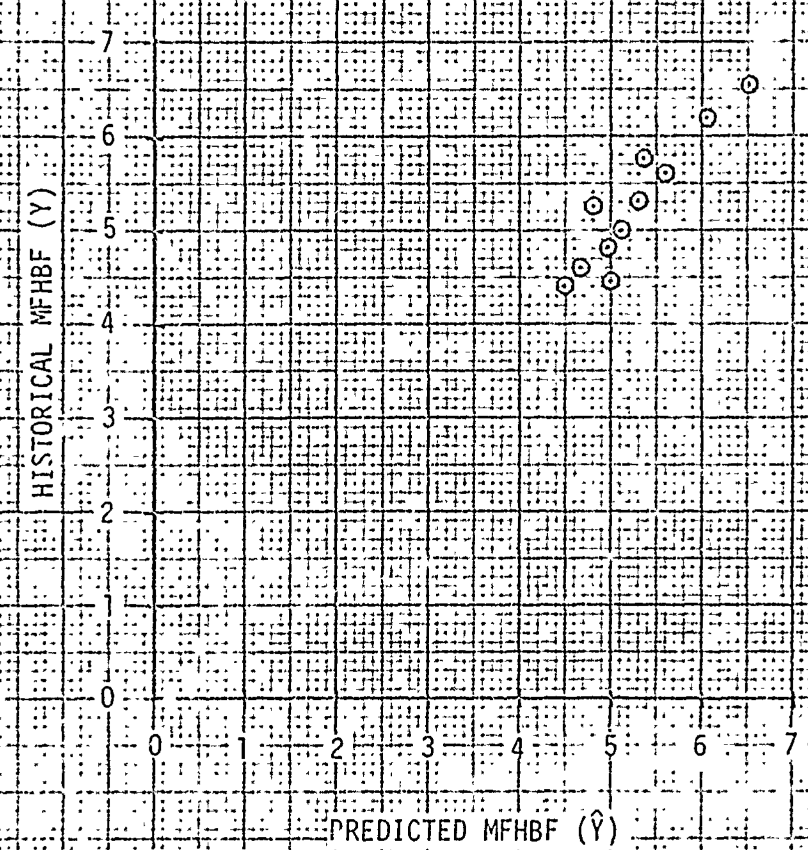


Figure 7-2. Predicted MFHBF vs Historical MFHBF For Rotary Wing Aircraft -- WUC 11000

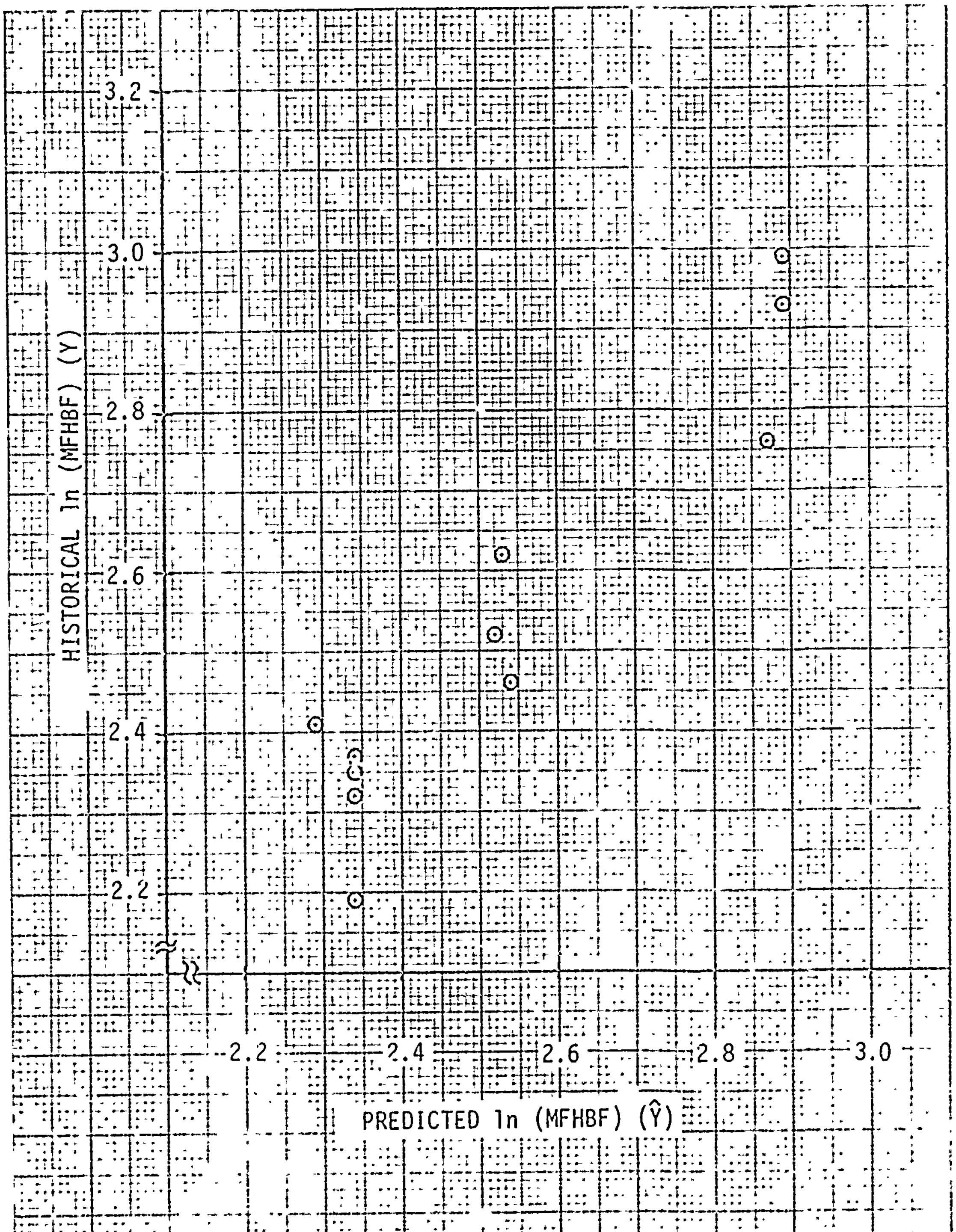


Figure 7-2 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Rotary Wing Aircraft -- WUC 13000

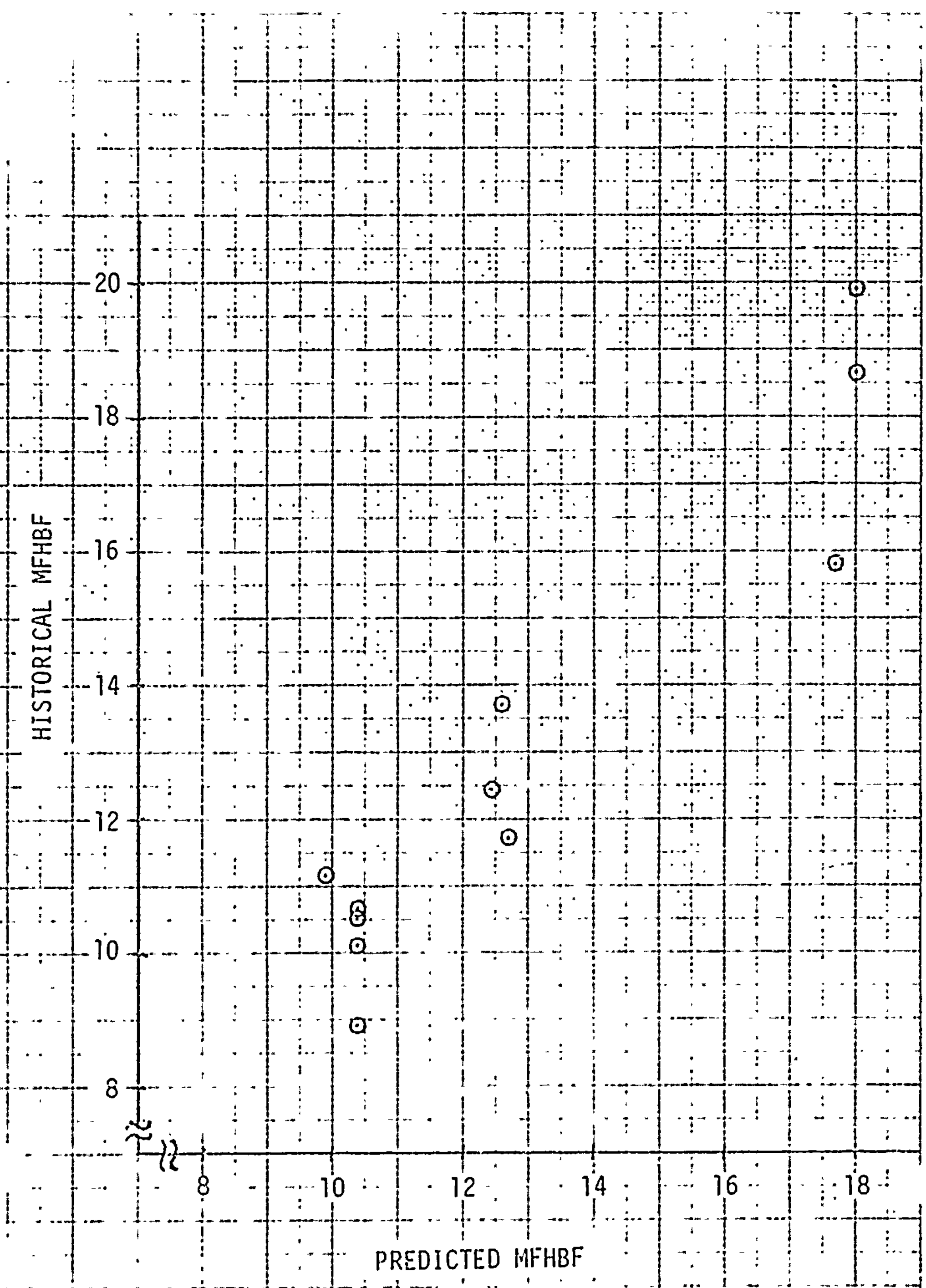


Figure 7-2 (Cont.). Predicted MFHBF vs Historical MFHBF For Rotary Wing Aircraft -- WUC 13000

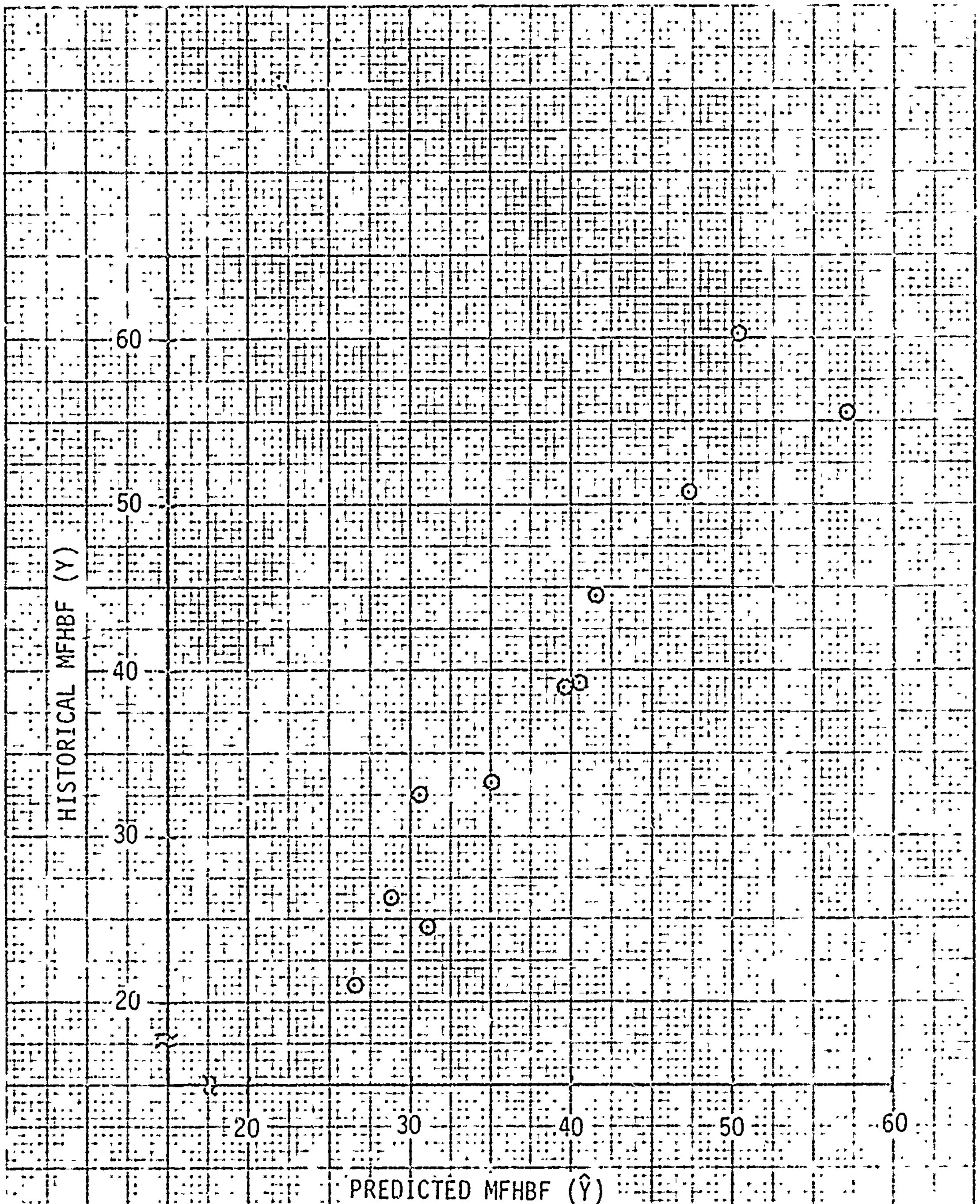


Figure 7-2 (Cont.). Predicted MFHBF vs Historical MFHBF For Rotary Wing Aircraft -- WUC 22000

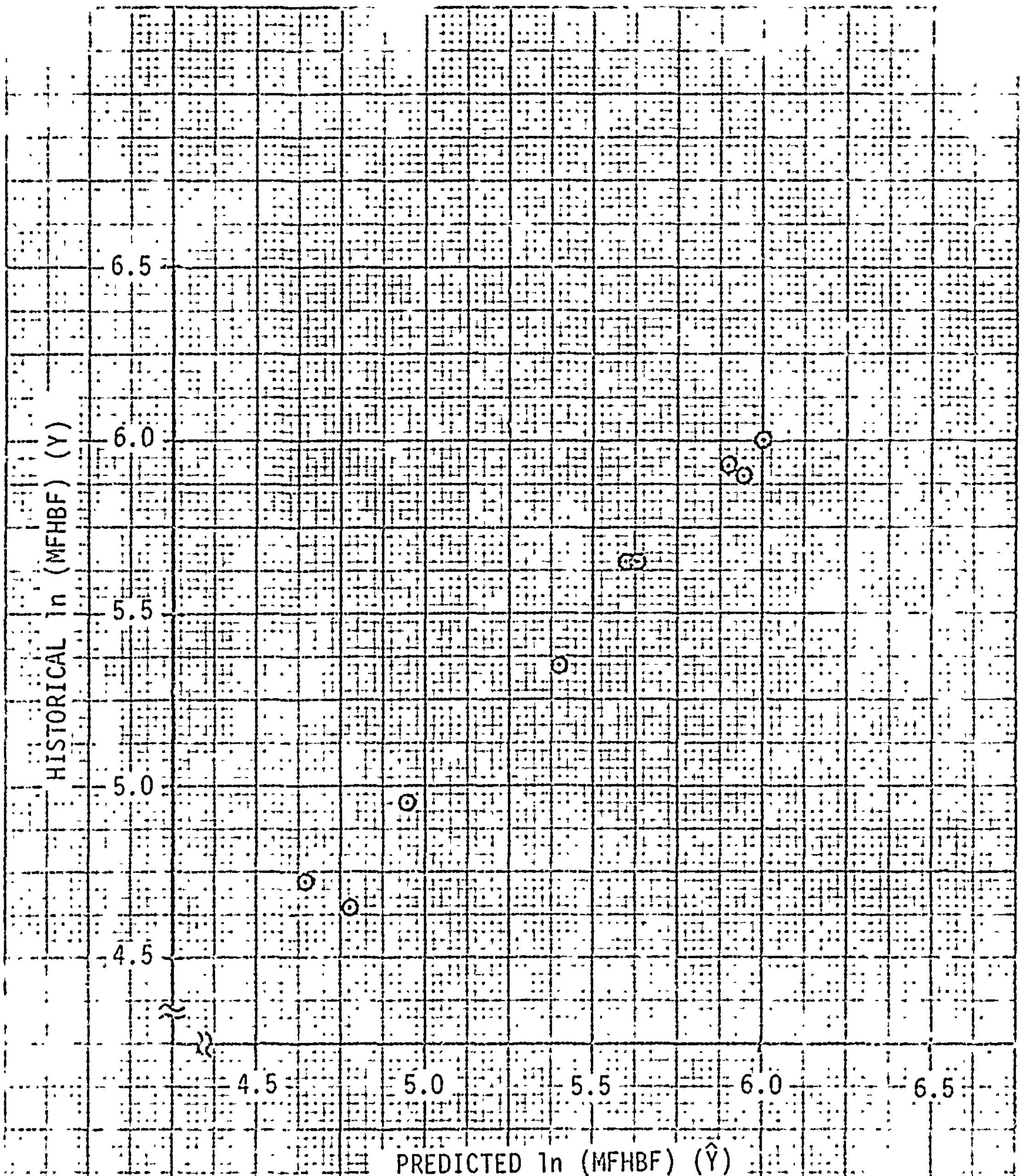


Figure 7-2 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Rotary Wing Aircraft -- WUC 41000

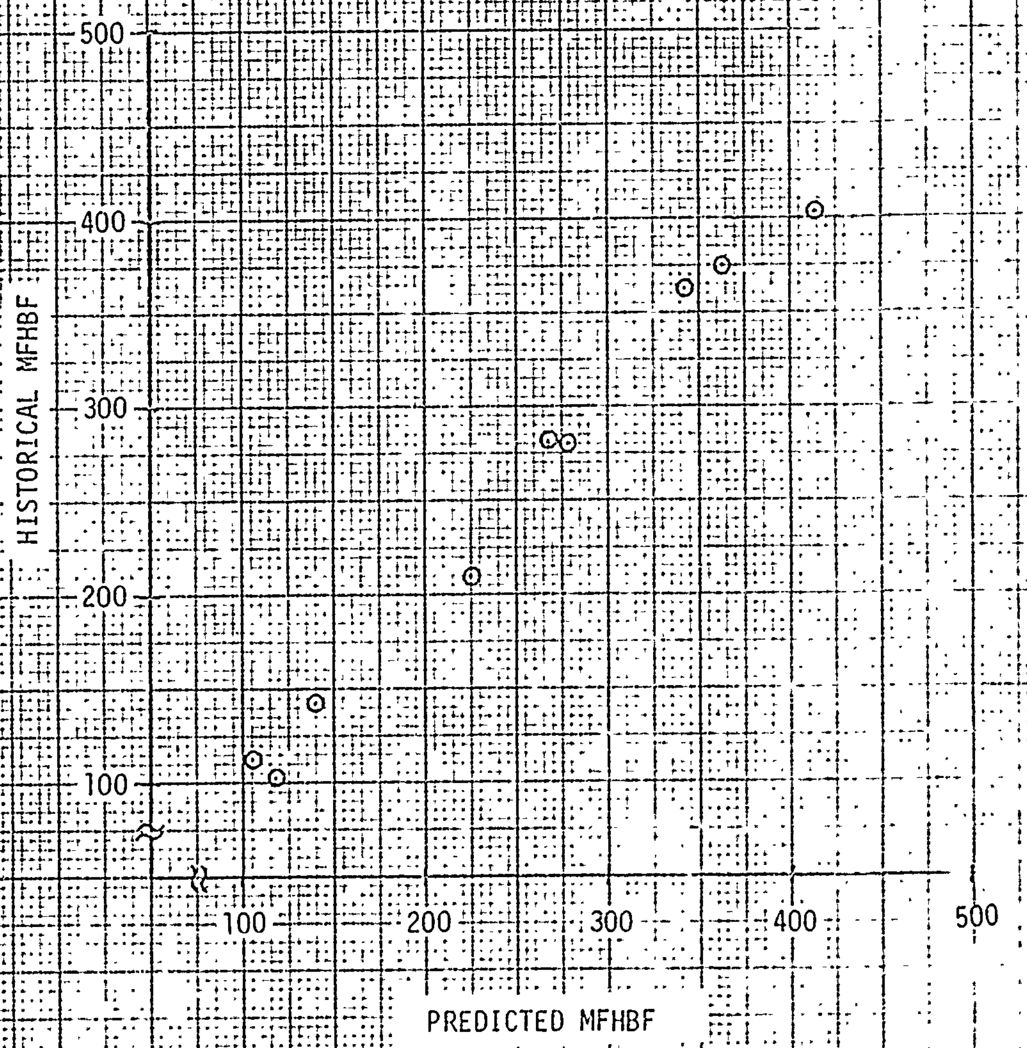


Figure 7-2 (Cont.). Predicted MFHBF vs Historical MFHBF
For Rotary Wing Aircraft -- WUC 41000

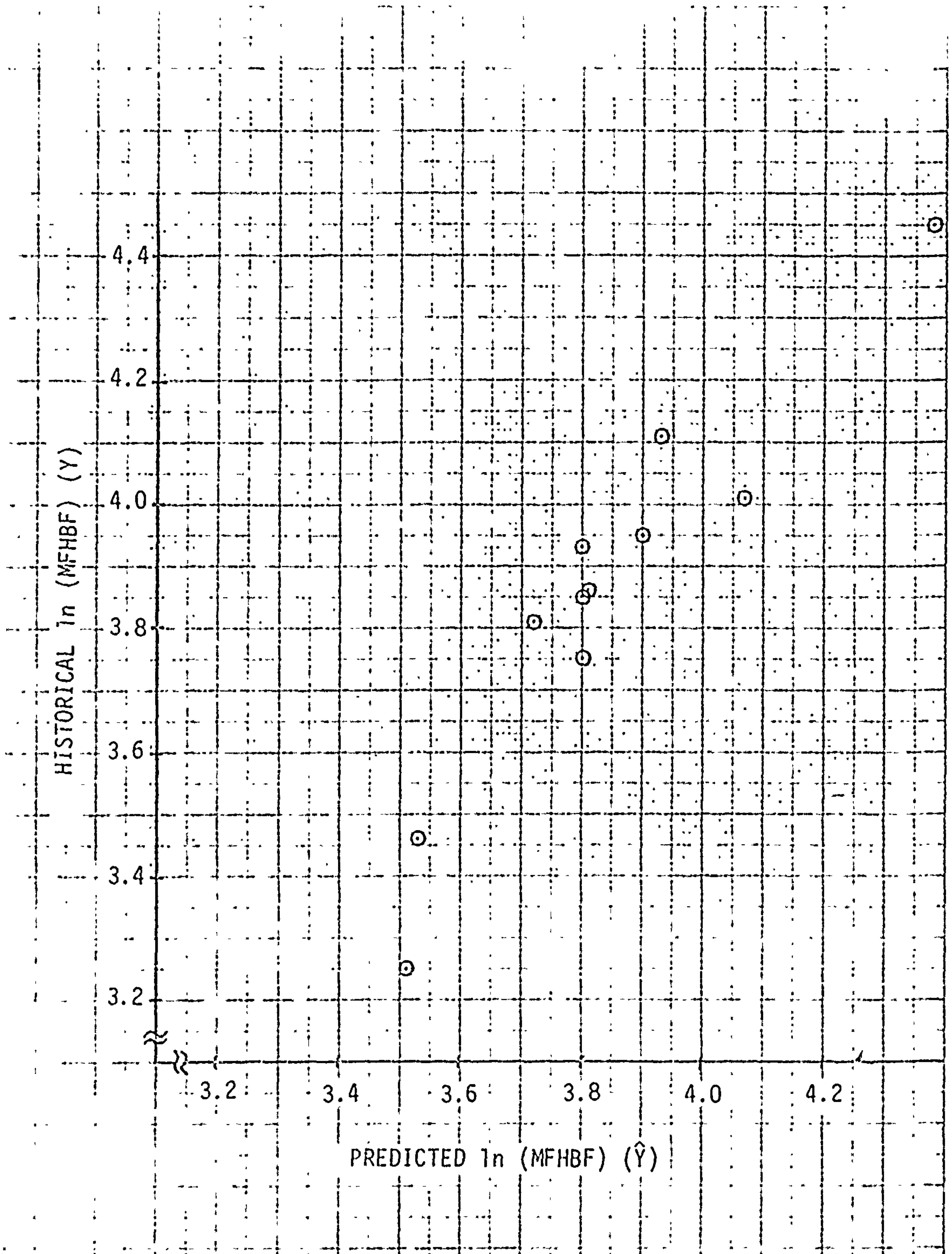


Figure 7-2 (Cont.). Predicted ln(MFHBF) vs Historical ln(MFHBF) For Rotary Wing Aircraft -- WUC 63000

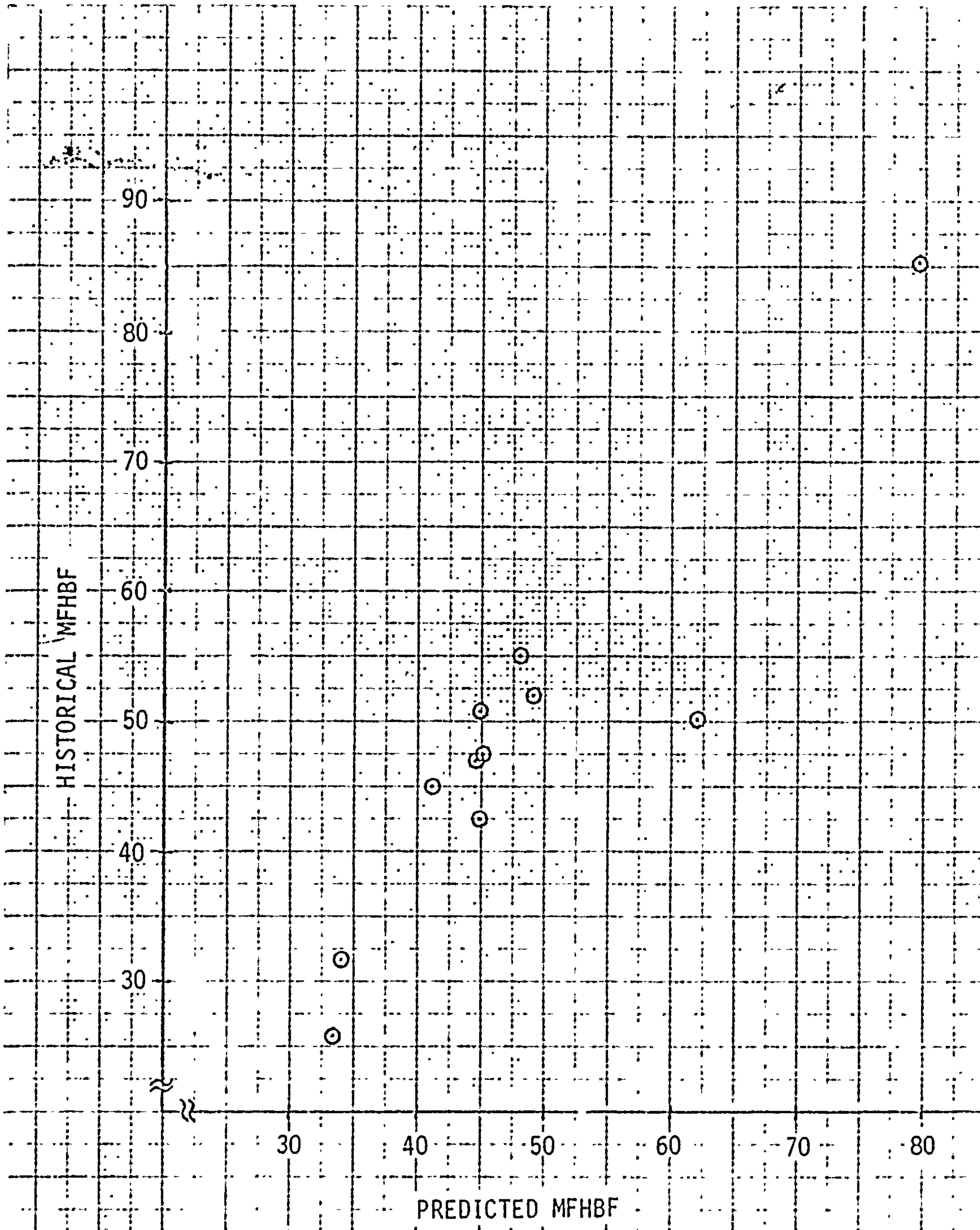


Figure 7-2 (Cont.). Predicted MFHBF vs Historical MFHBF For Rotary Wing Aircraft -- WUC 63000

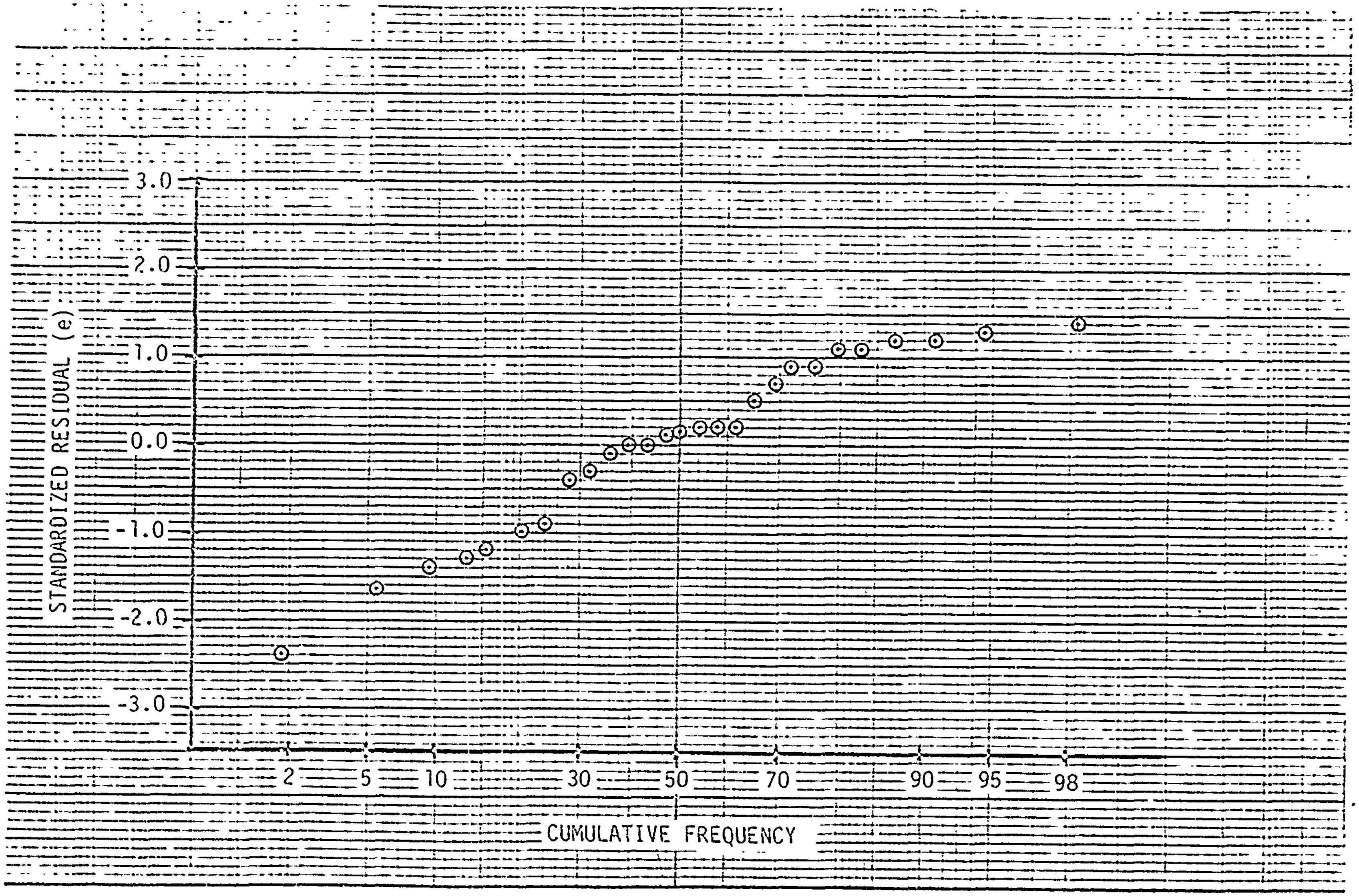


Figure 7-3. Normal Plot of Standardized Residuals For Fixed Wing Aircraft -- WUC 11000

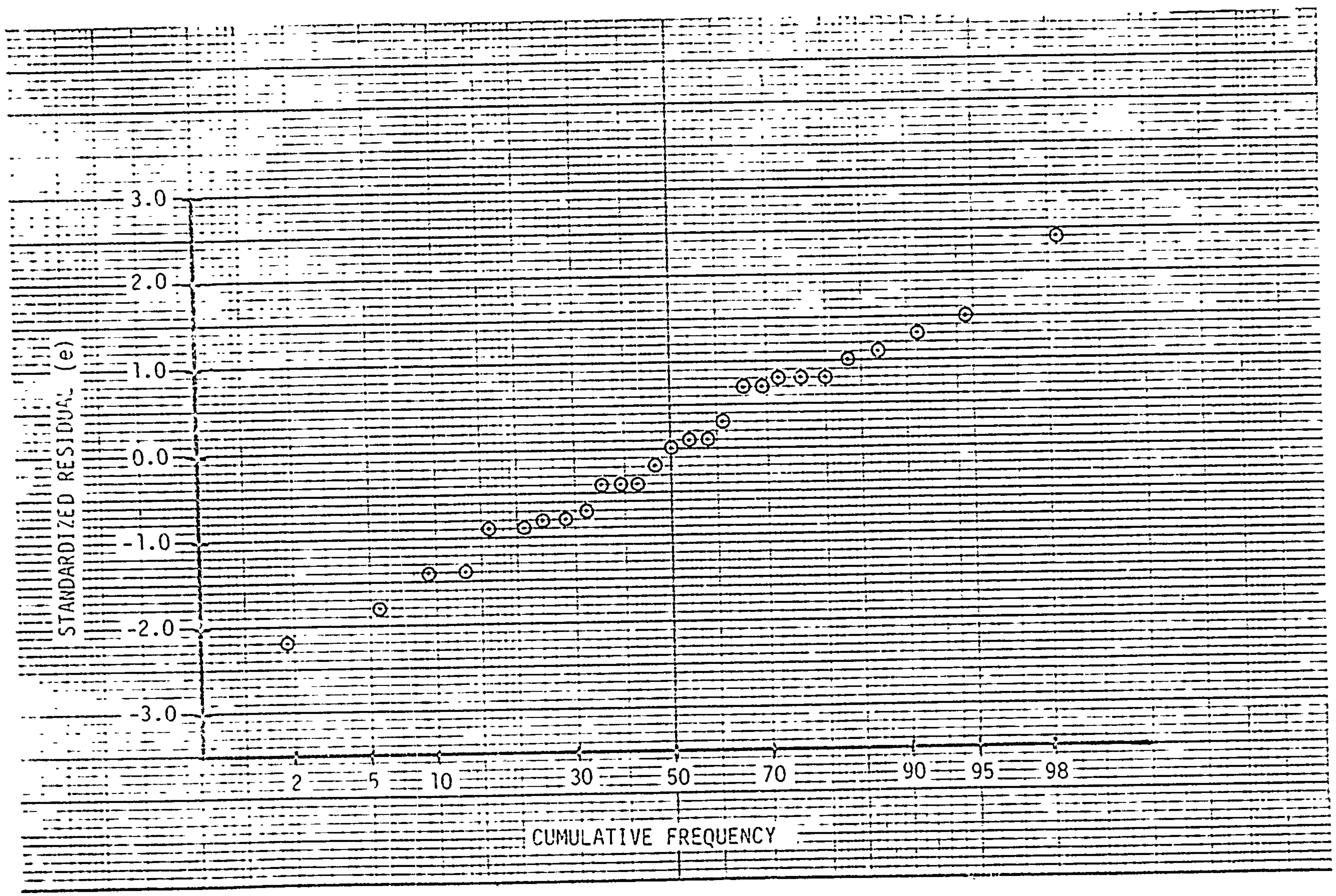


Figure 7-3 (Cont.). Normal Plots of Standardized Residuals For Fixed Wing Aircraft -- WUC 13000

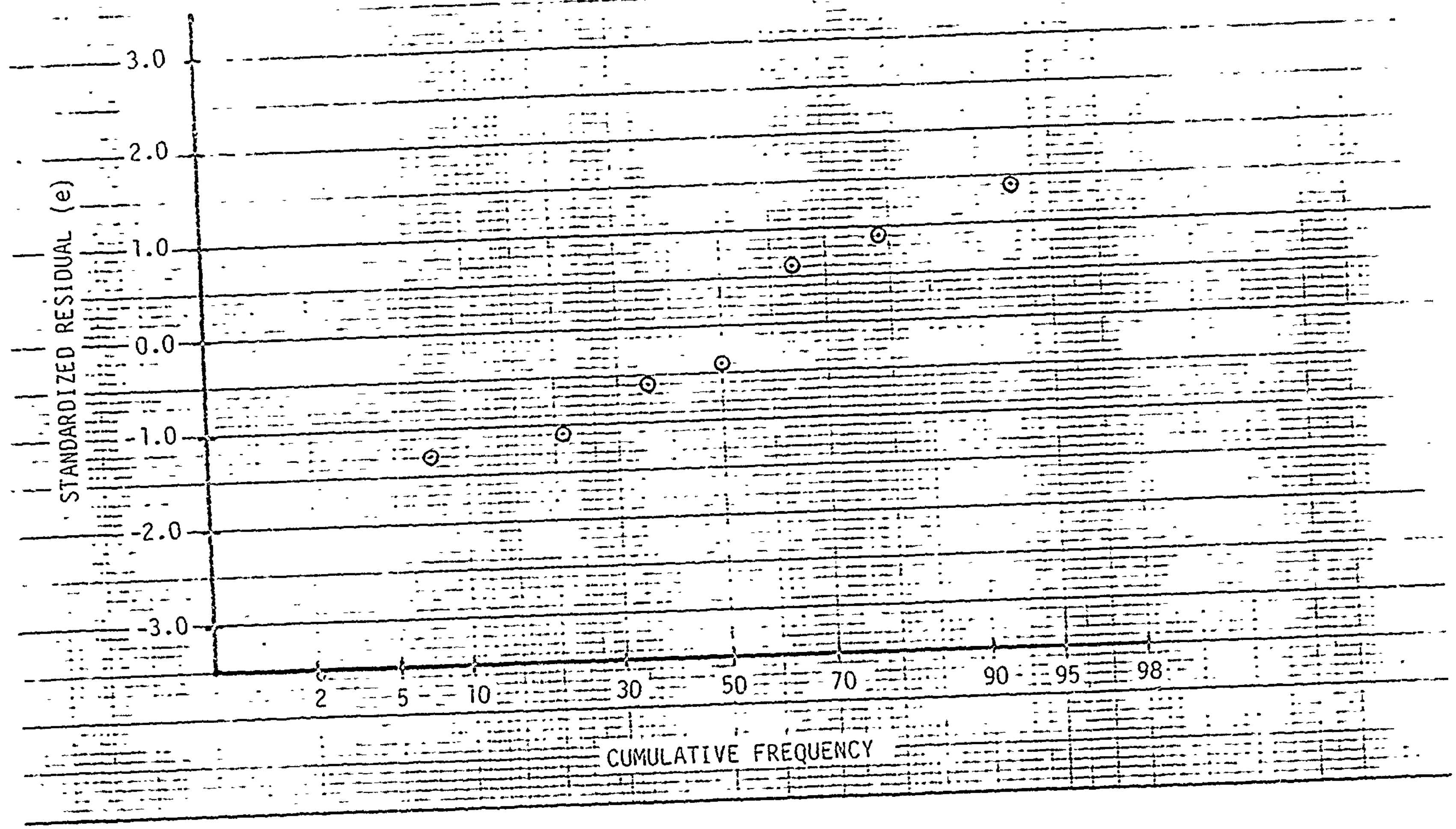


Figure 7-3 (Cont.). Normal Plot of Standardized Residuals For Fixed Wing Aircraft -- WUC 27000

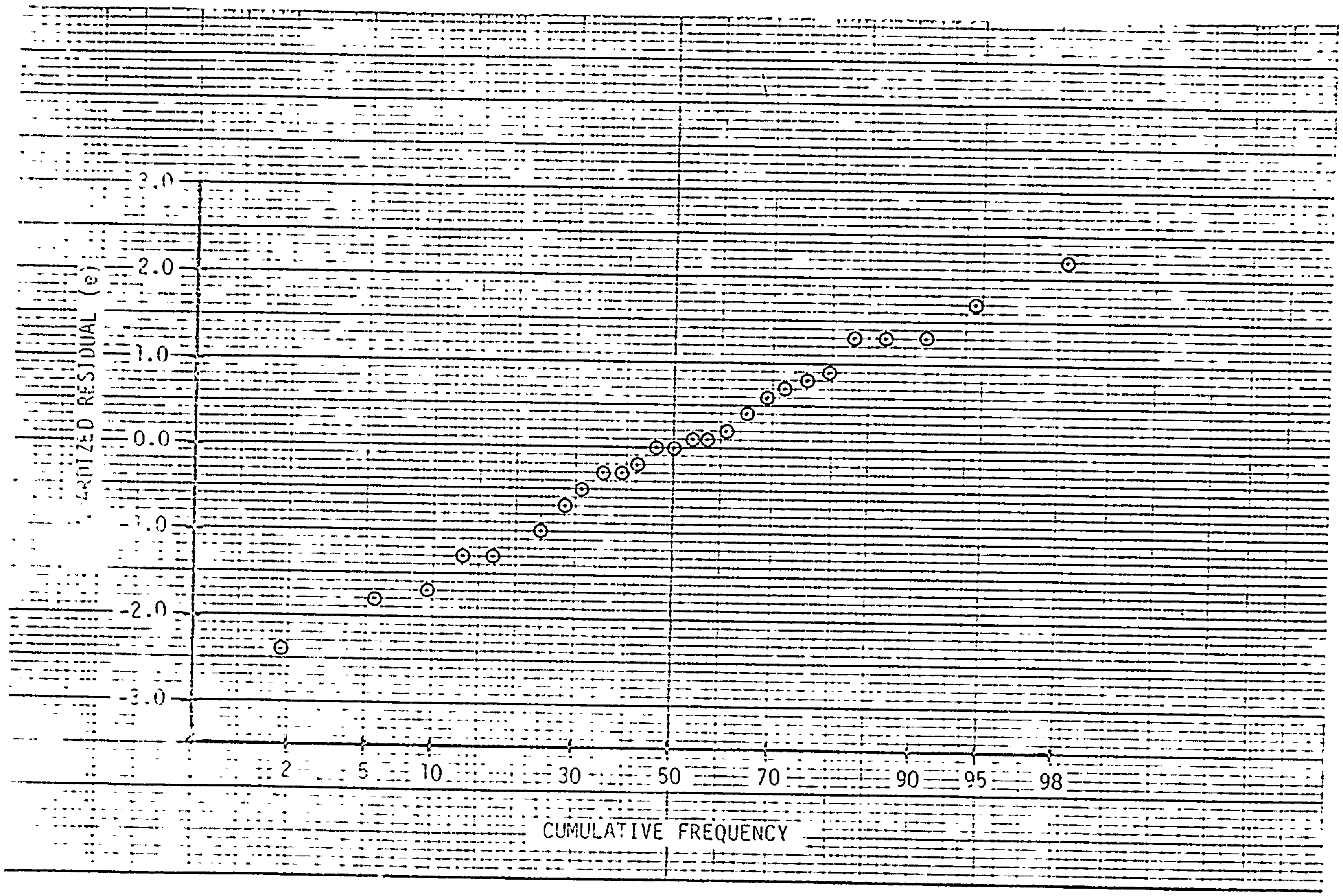


Figure 7-3 (Cont.). Normal Plot of Standardized Residuals For Fixed Wing Aircraft -- WUC 41000

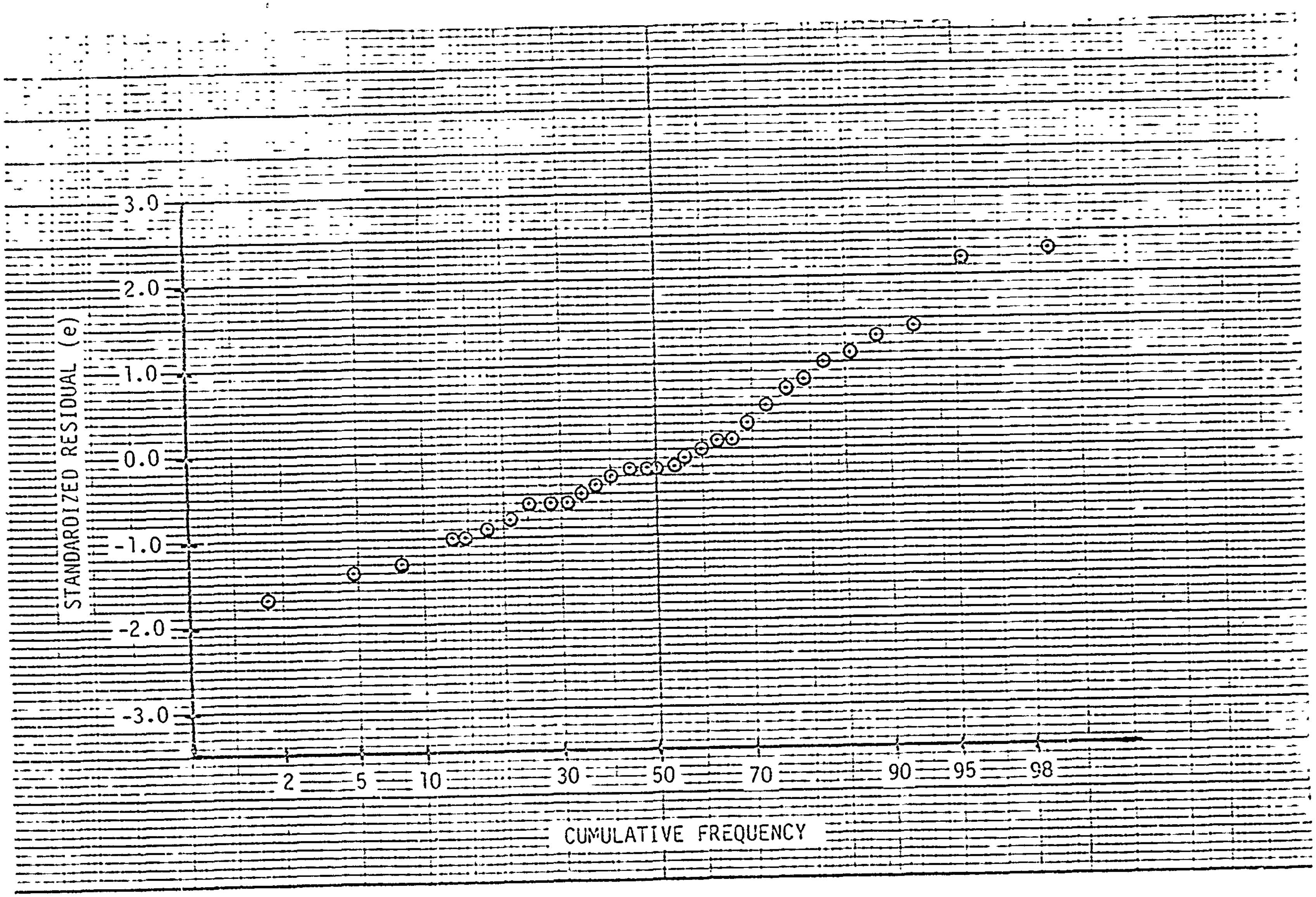


Figure 7-3 (Cont.). Normal Plot of Standardized Residuals For Fixed Wing Aircraft -- WUC 63000

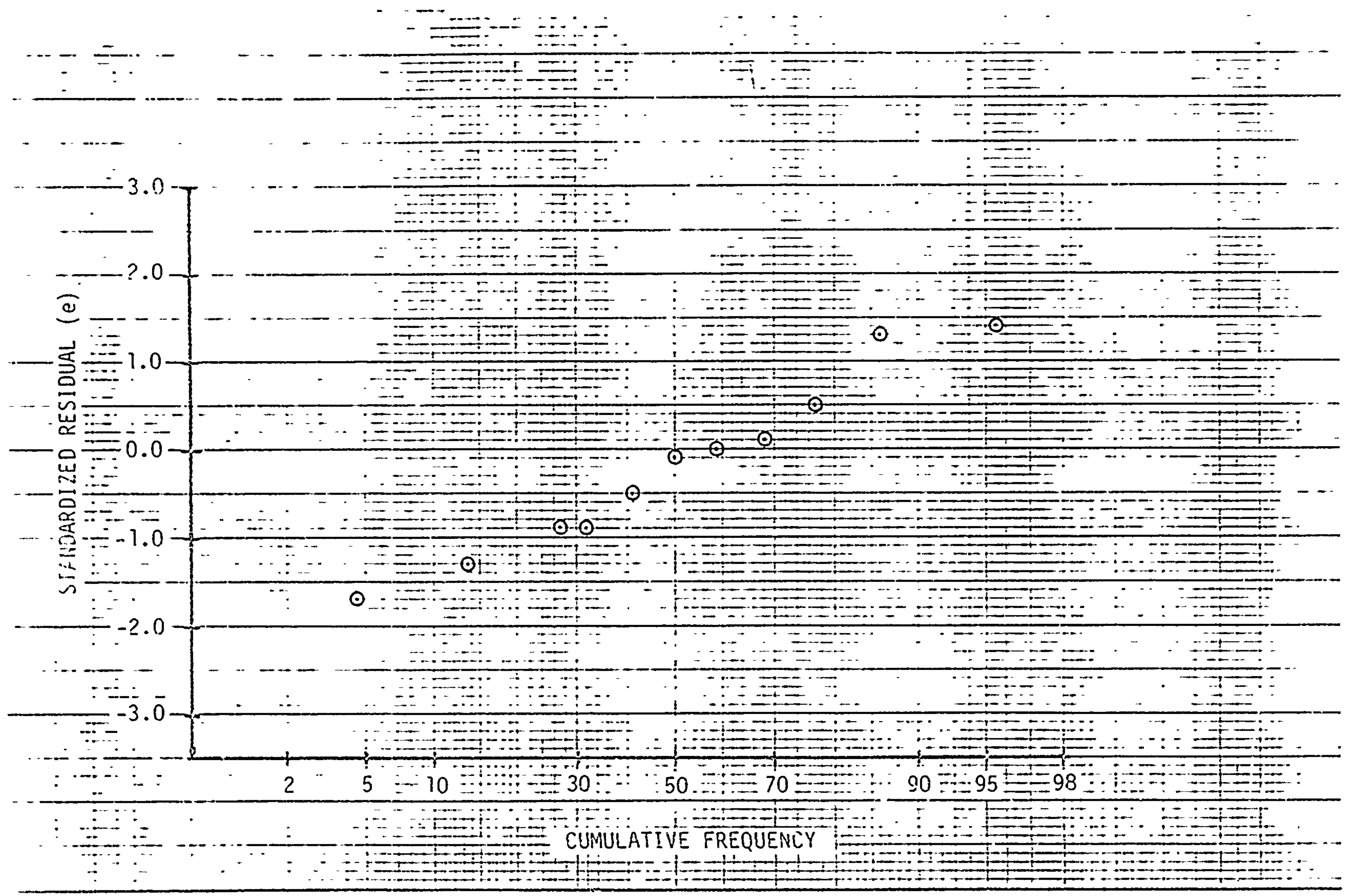


Figure 7-4. Normal Plot of Standardized Residuals For Rotary Wing Aircraft -- WUC 11000

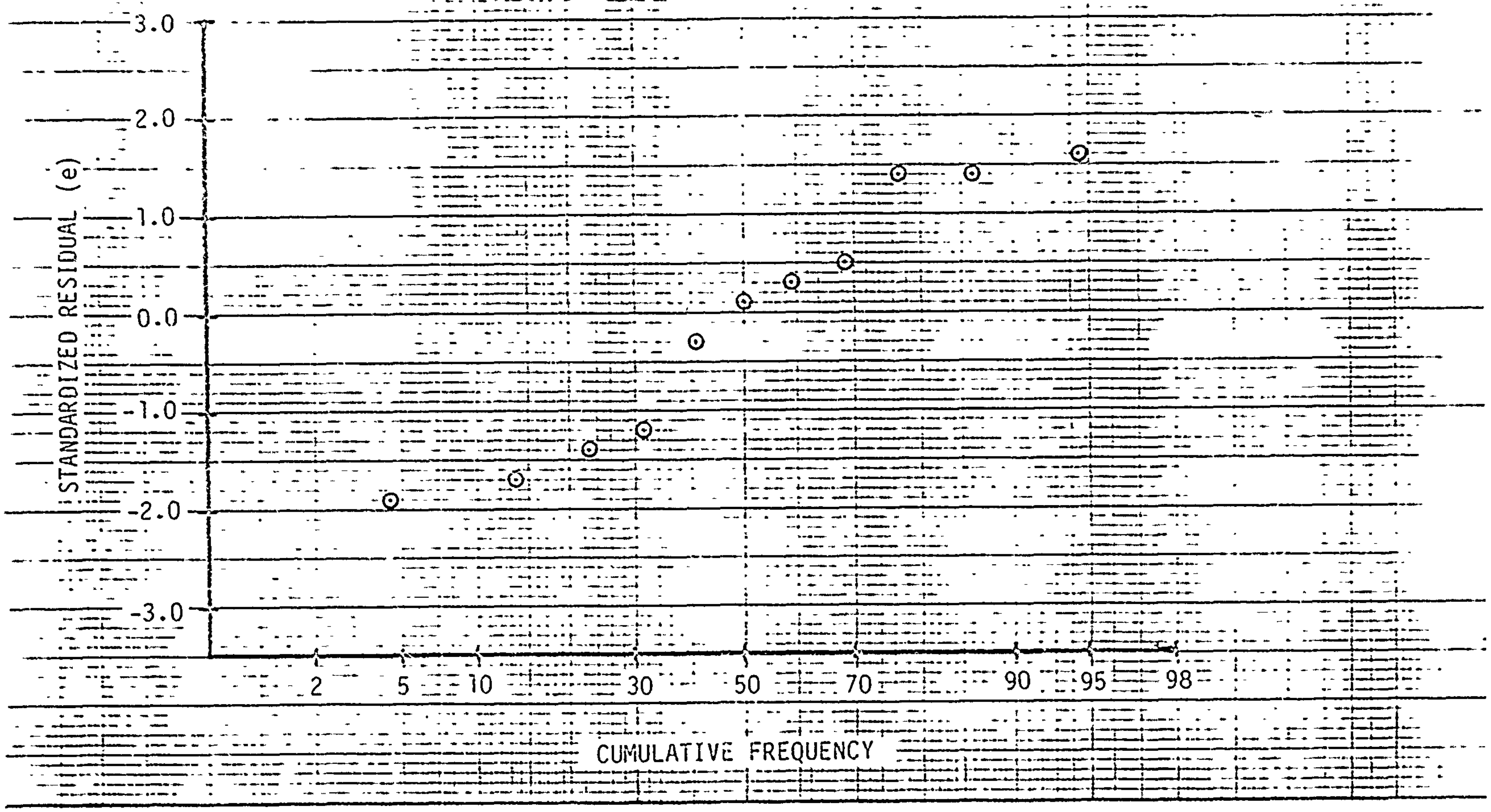


Figure 7-4 (Cont.). Normal Plot of Standardized Residuals For Rotary Wing Aircraft -- WUC 13000

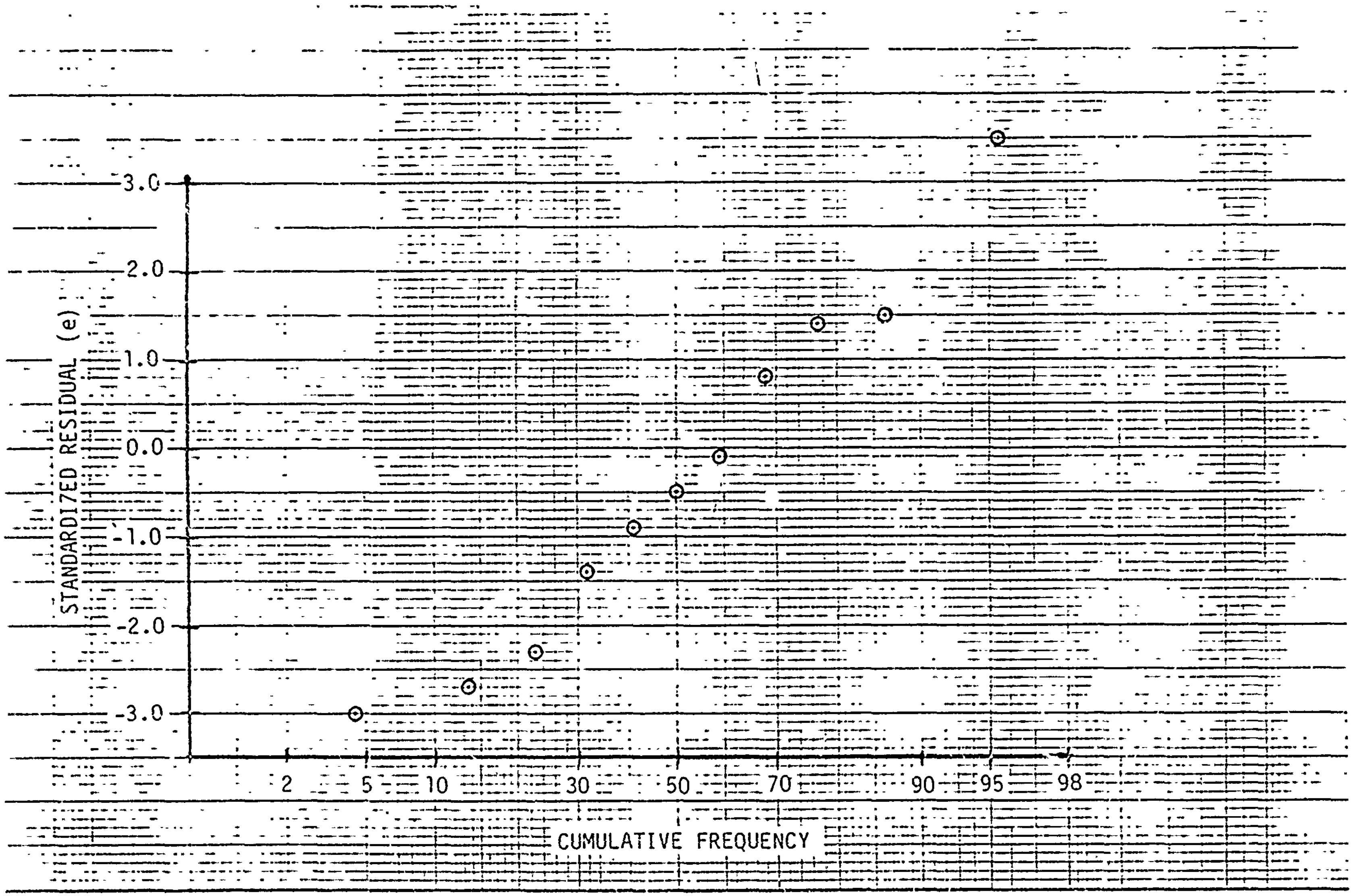


Figure 7-4 (Cont.). Normal Plot of Standardized Residuals For Rotary Wing Aircraft -- WUC 22000

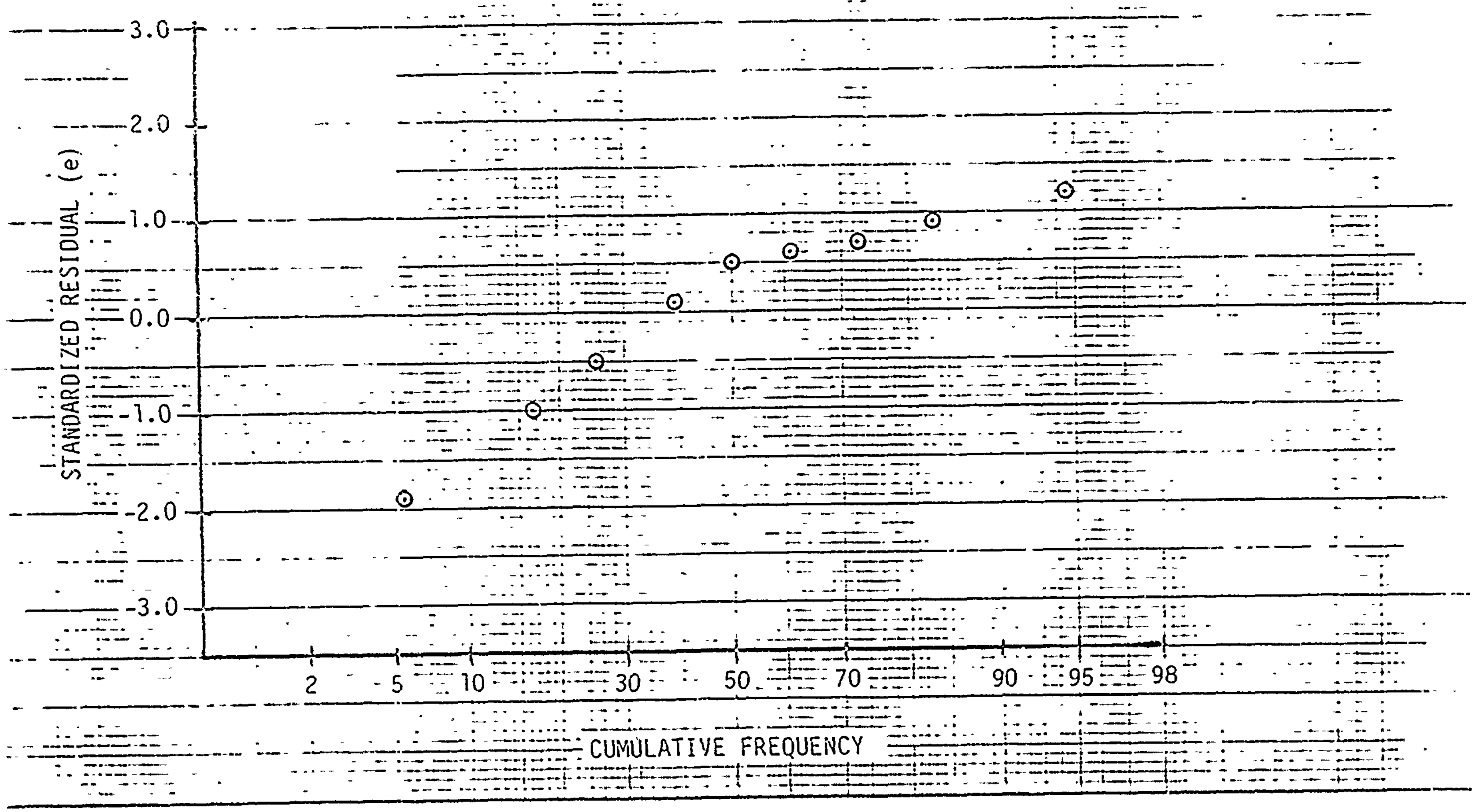


Figure 7-4 (Cont.). Normal Plot of Standardized Residuals For Rotary Wing Aircraft -- WUC 41000

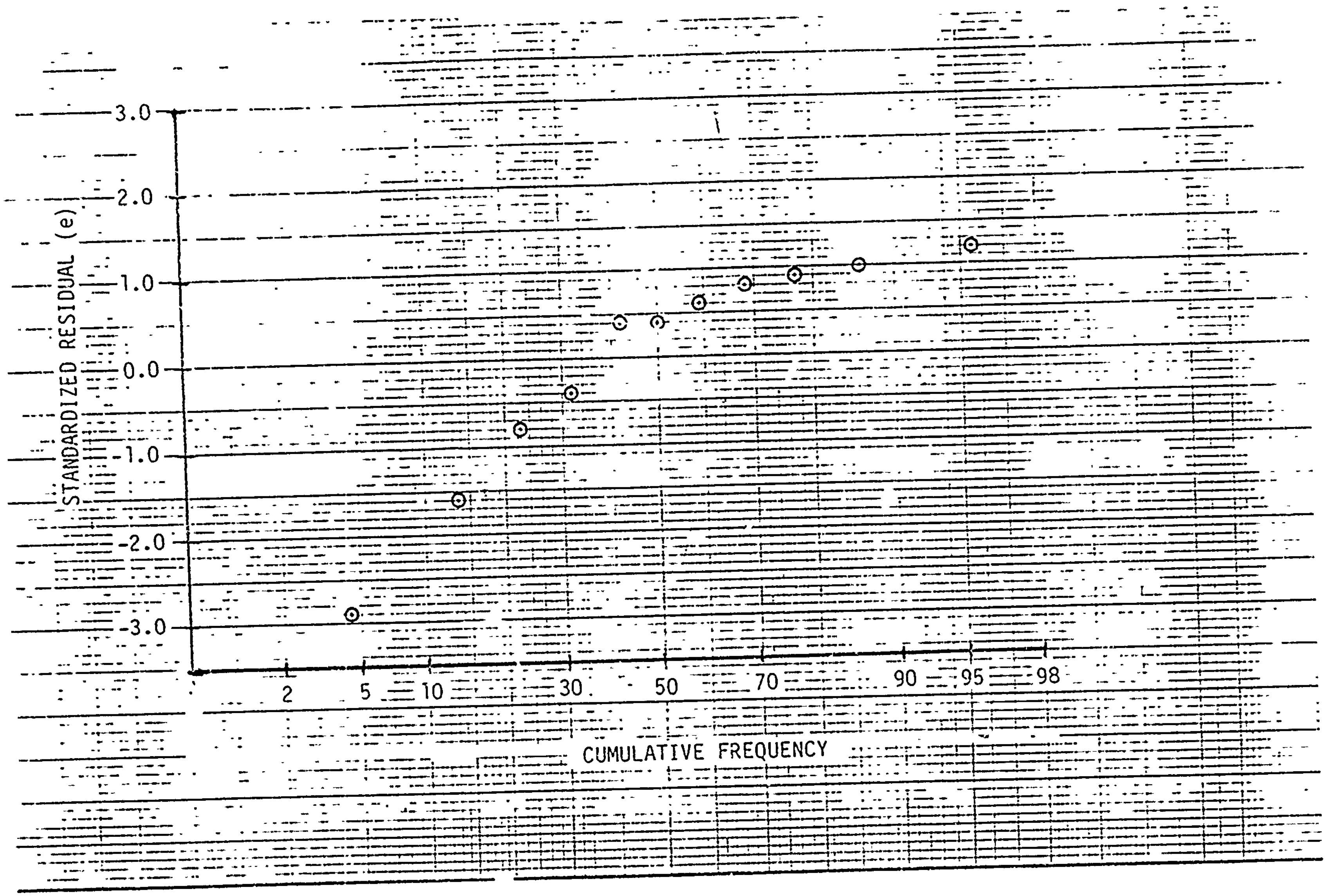


Figure 7-4 (Cont.). Normal Plot of Standardized Residuals For Rotary Wing Aircraft -- WUC 63000

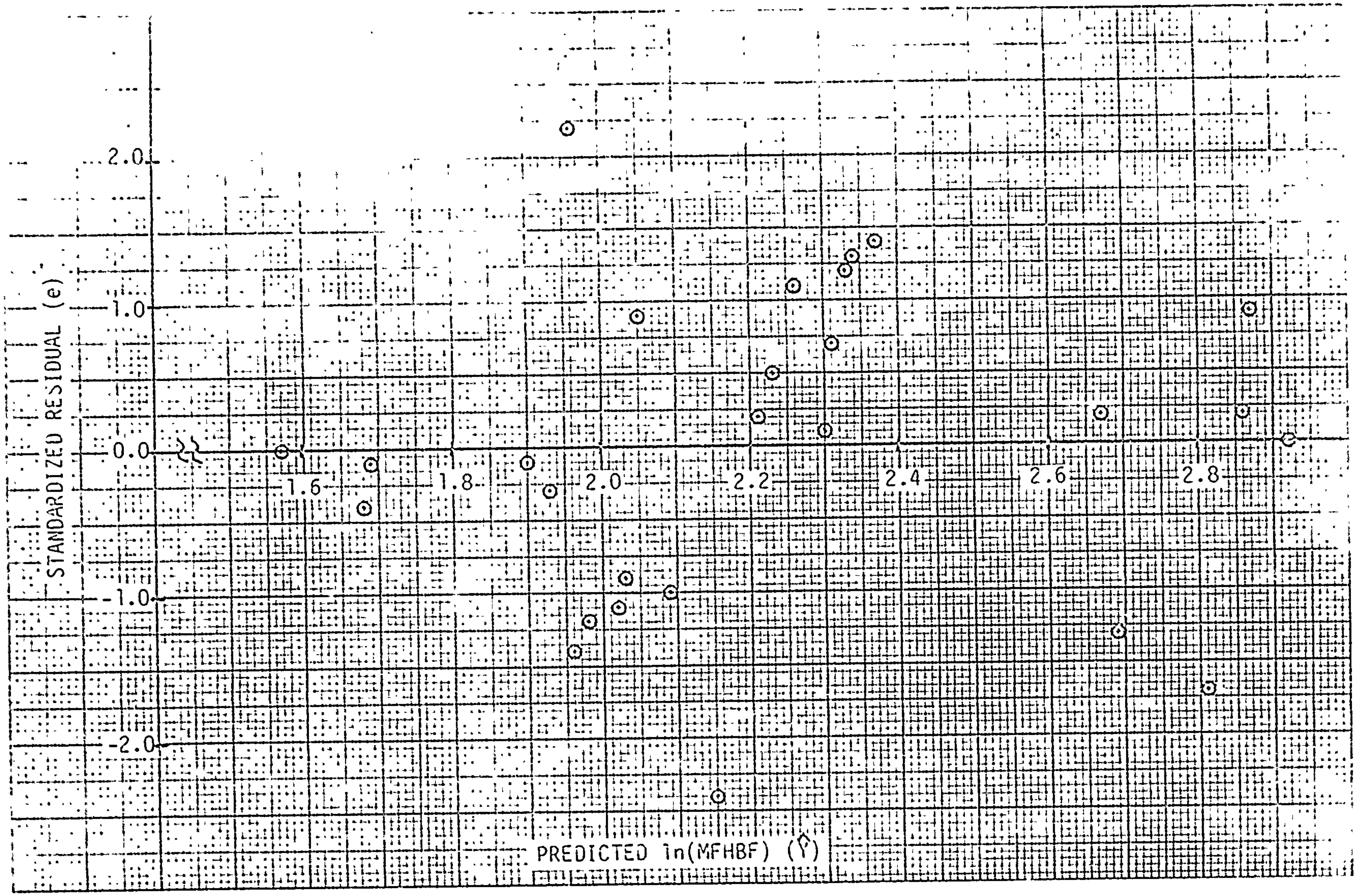


Figure 7-5. Predicted ln(MFHBF) vs Standardized Residuals For Fixed Wing Aircraft -- WUC 11000

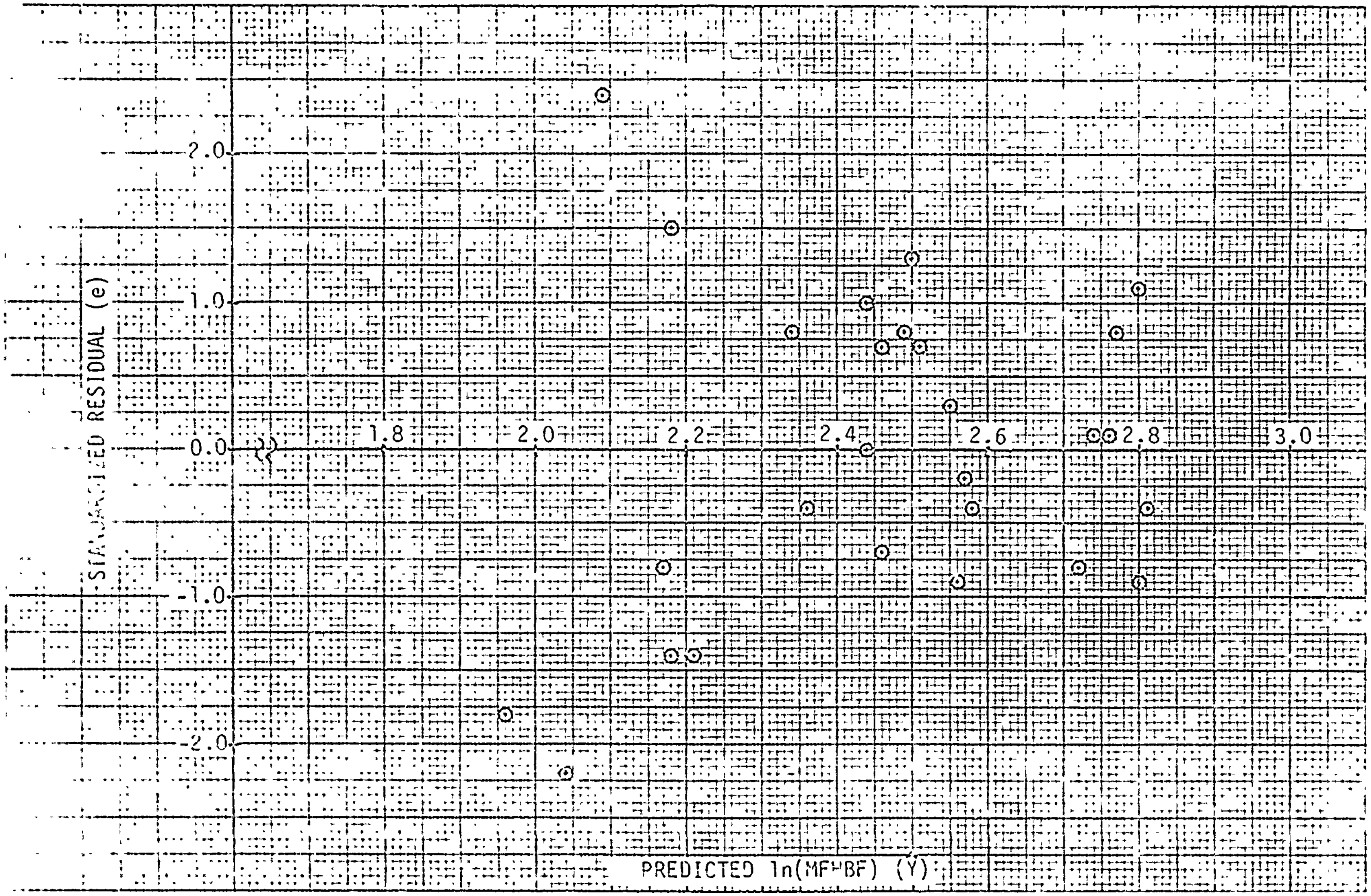


Figure 7-5 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Fixed Wing Aircraft -- WUC 13000

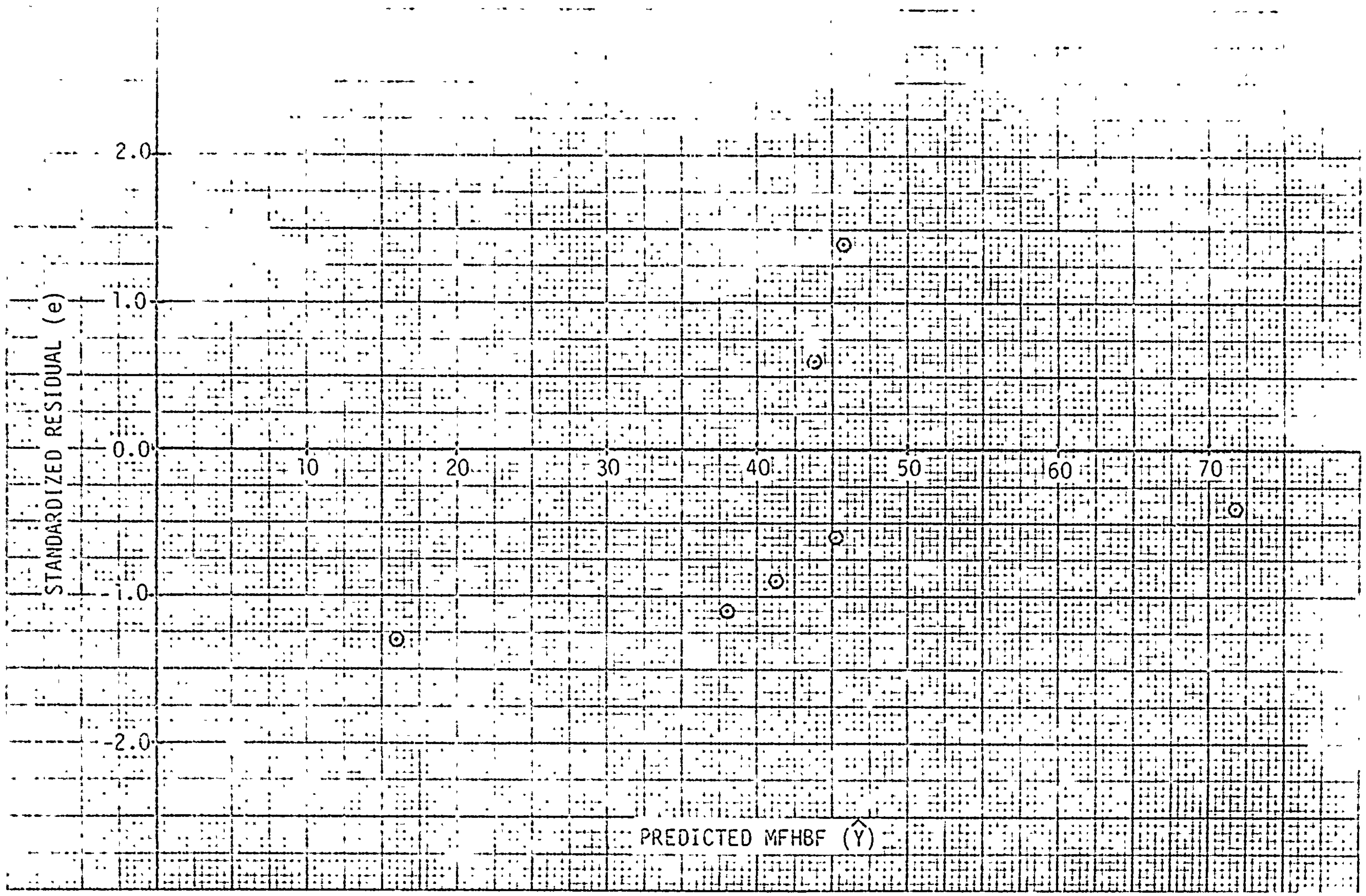


Figure 7-5 (Cont.). Predicted MFHBF vs Standardized Residuals For Fixed Wing Aircraft -- WUC 27000

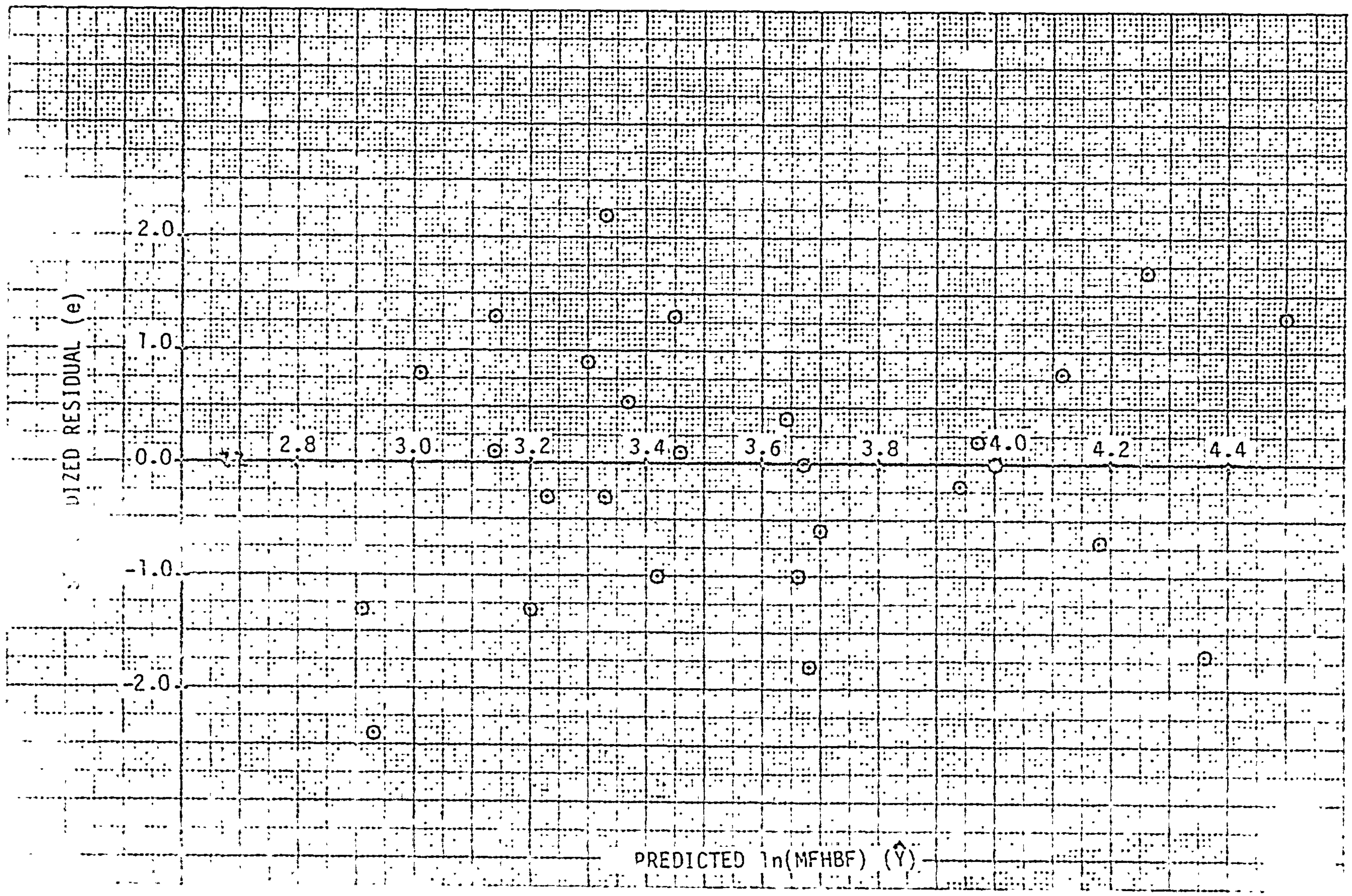


Figure 7-5 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Fixed Wing Aircraft -- WUC 410(

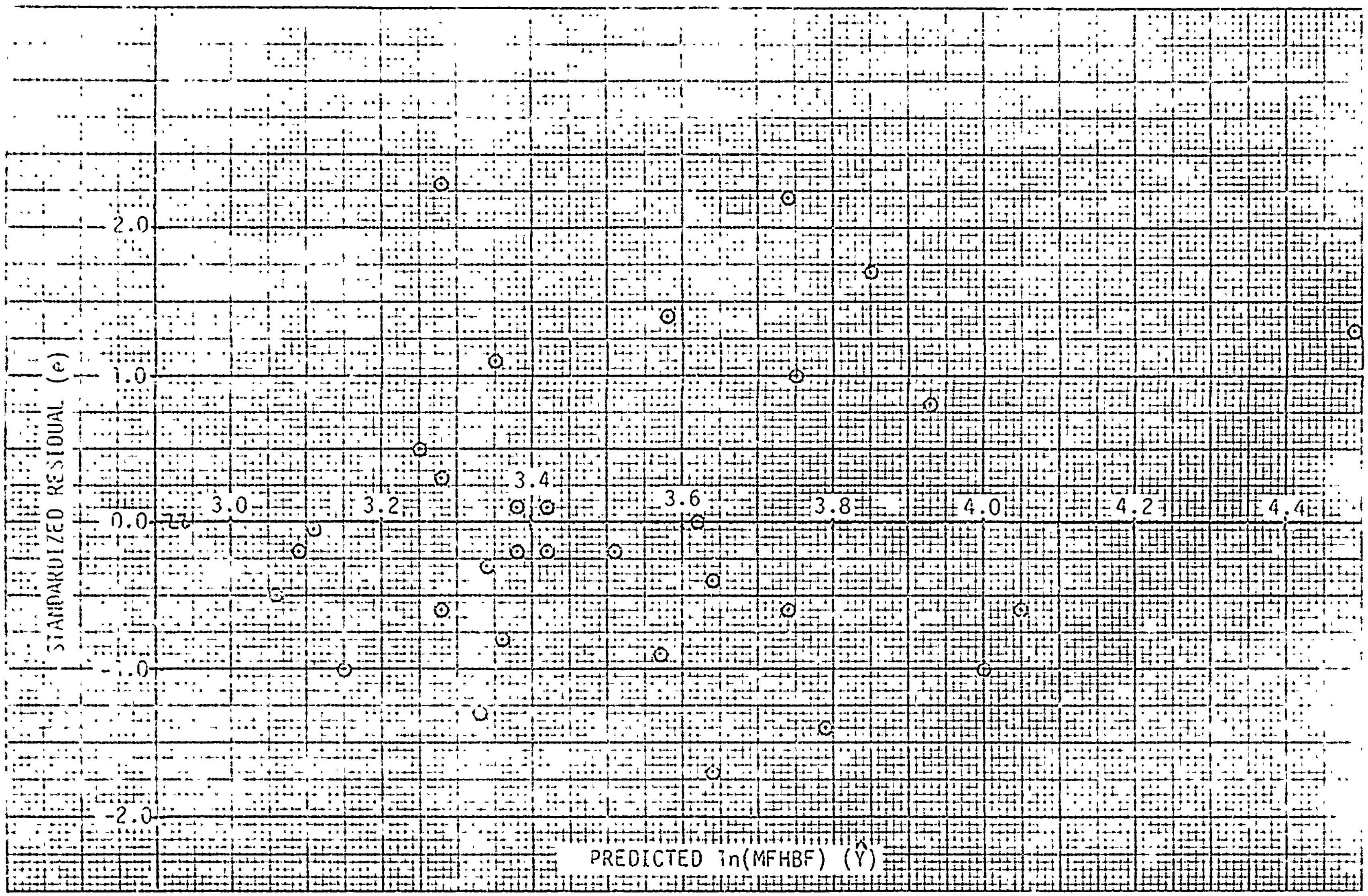
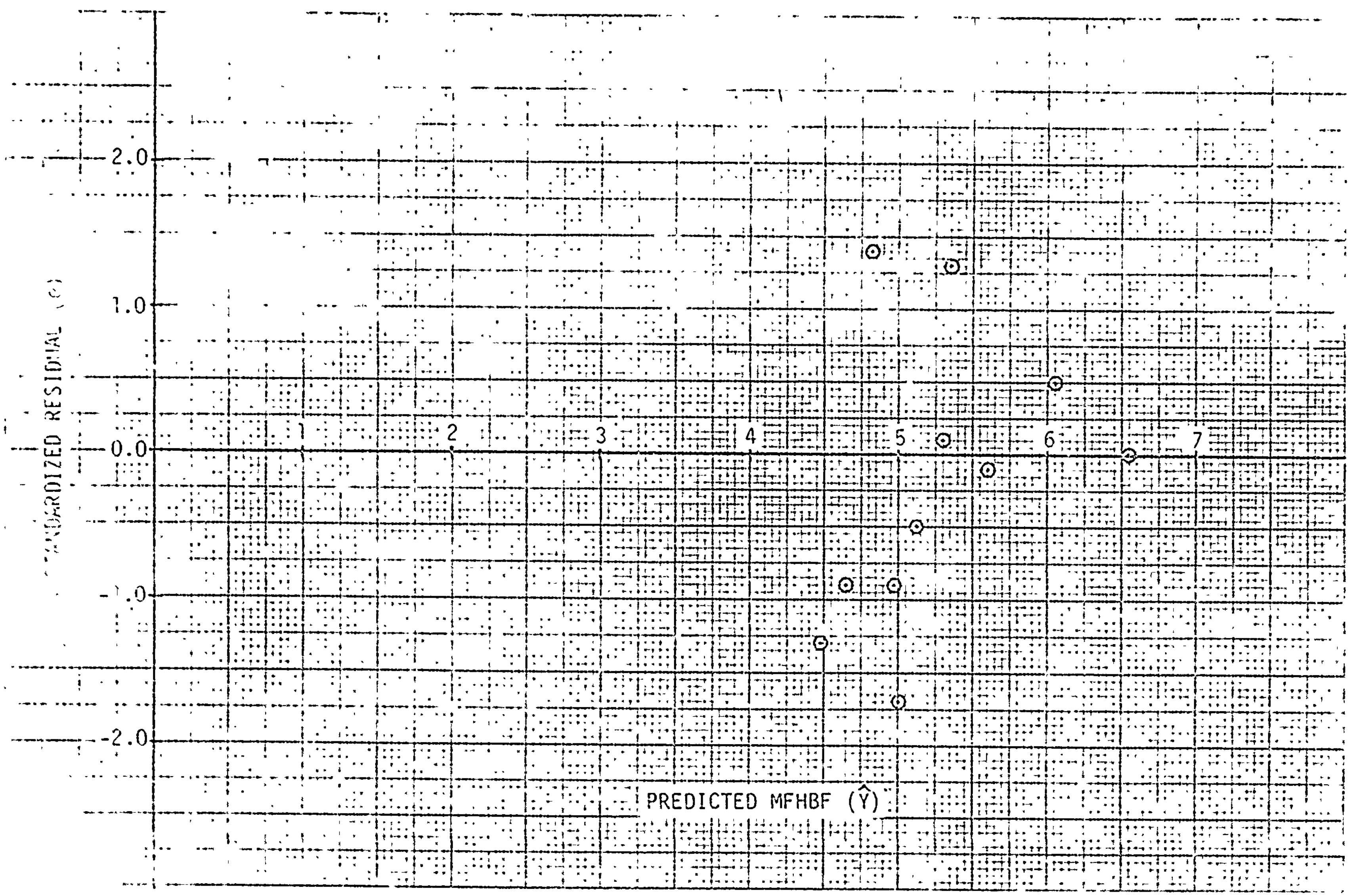


Figure 7-5 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Fixed Wing Aircraft -- WUC 63000



…re 7-6. Predicted MFHBF vs Standardized Residuals For Rotary Wing Aircraft -- WUC 11000

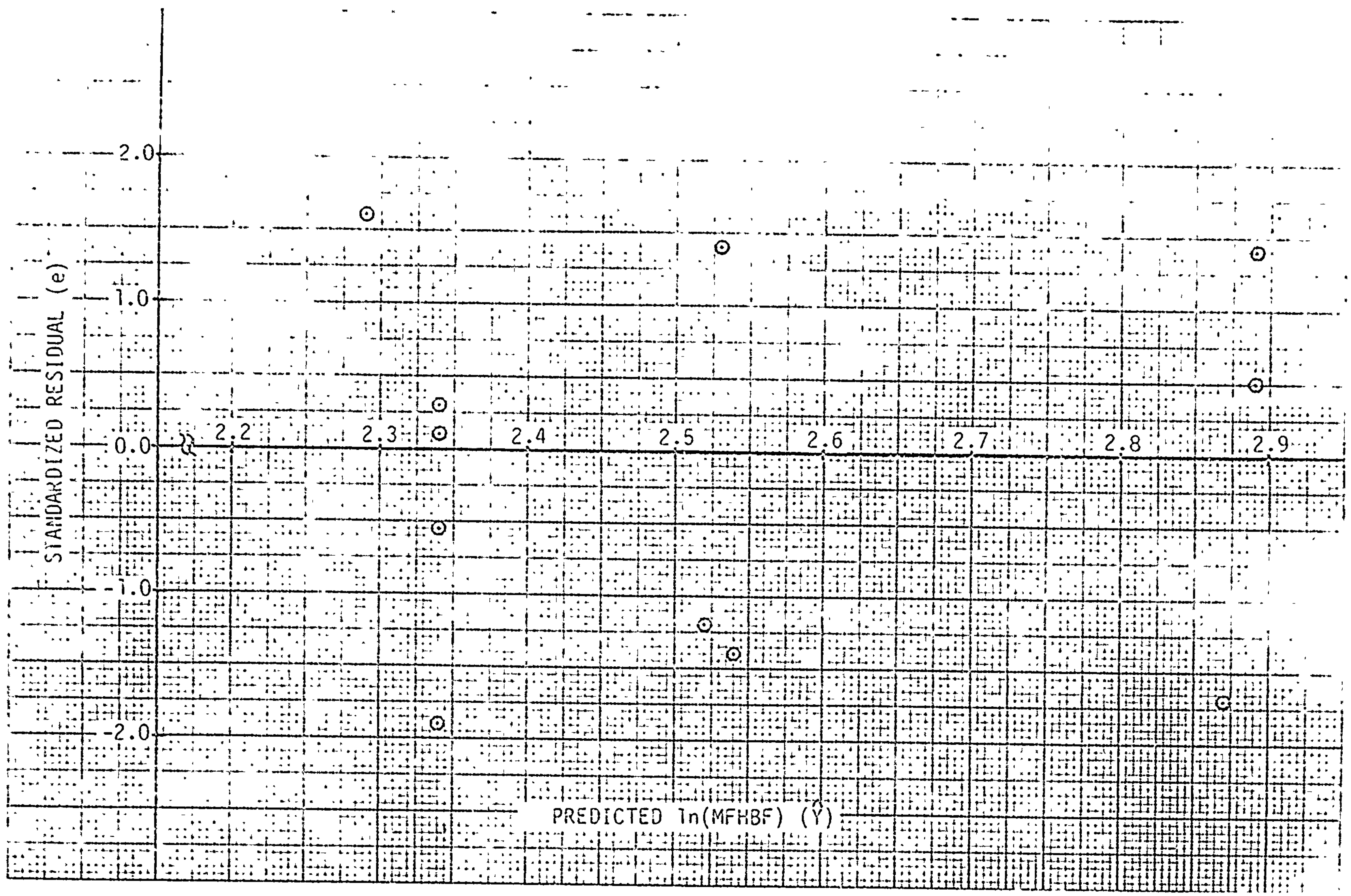


Figure 7-6 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Rotary Wing Aircraft -- WUC 13000

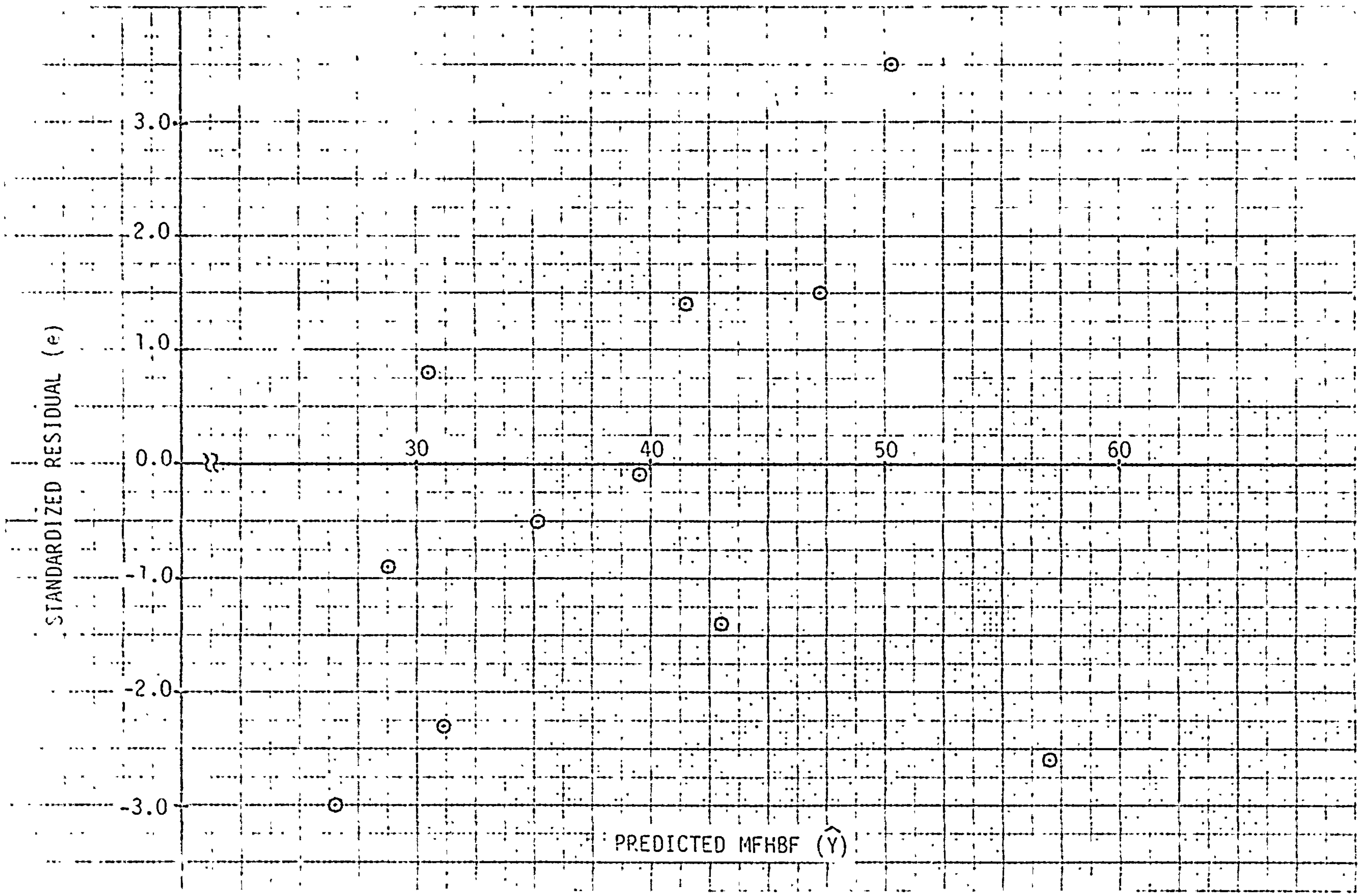


Figure 7-6 (Cont.). Predicted MFHBF vs Standardized Residuals For Rotary Wing Aircraft -- WUC 22000

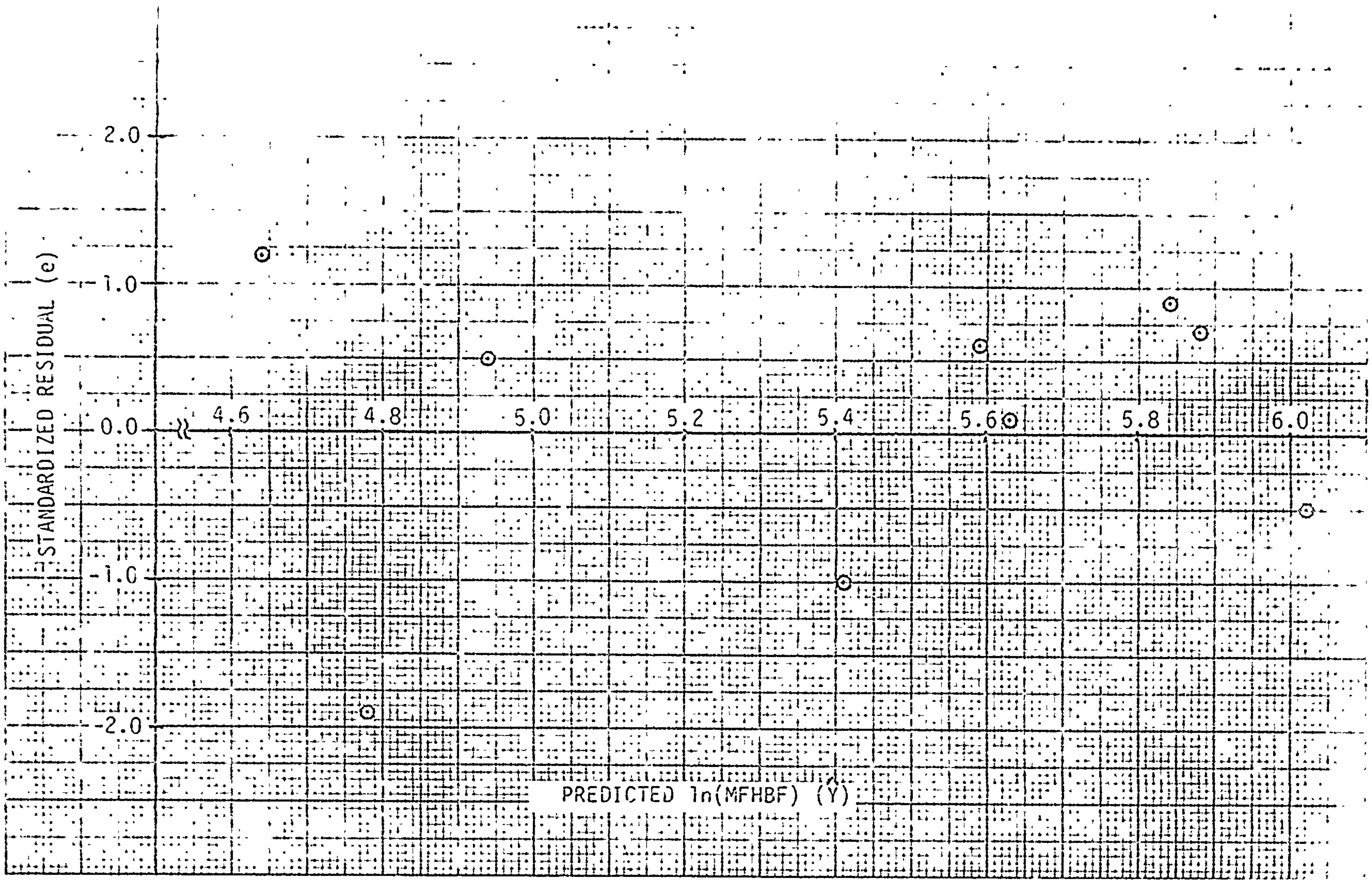


Figure 7-6 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Rotary Wing Aircraft -- WUC 41000

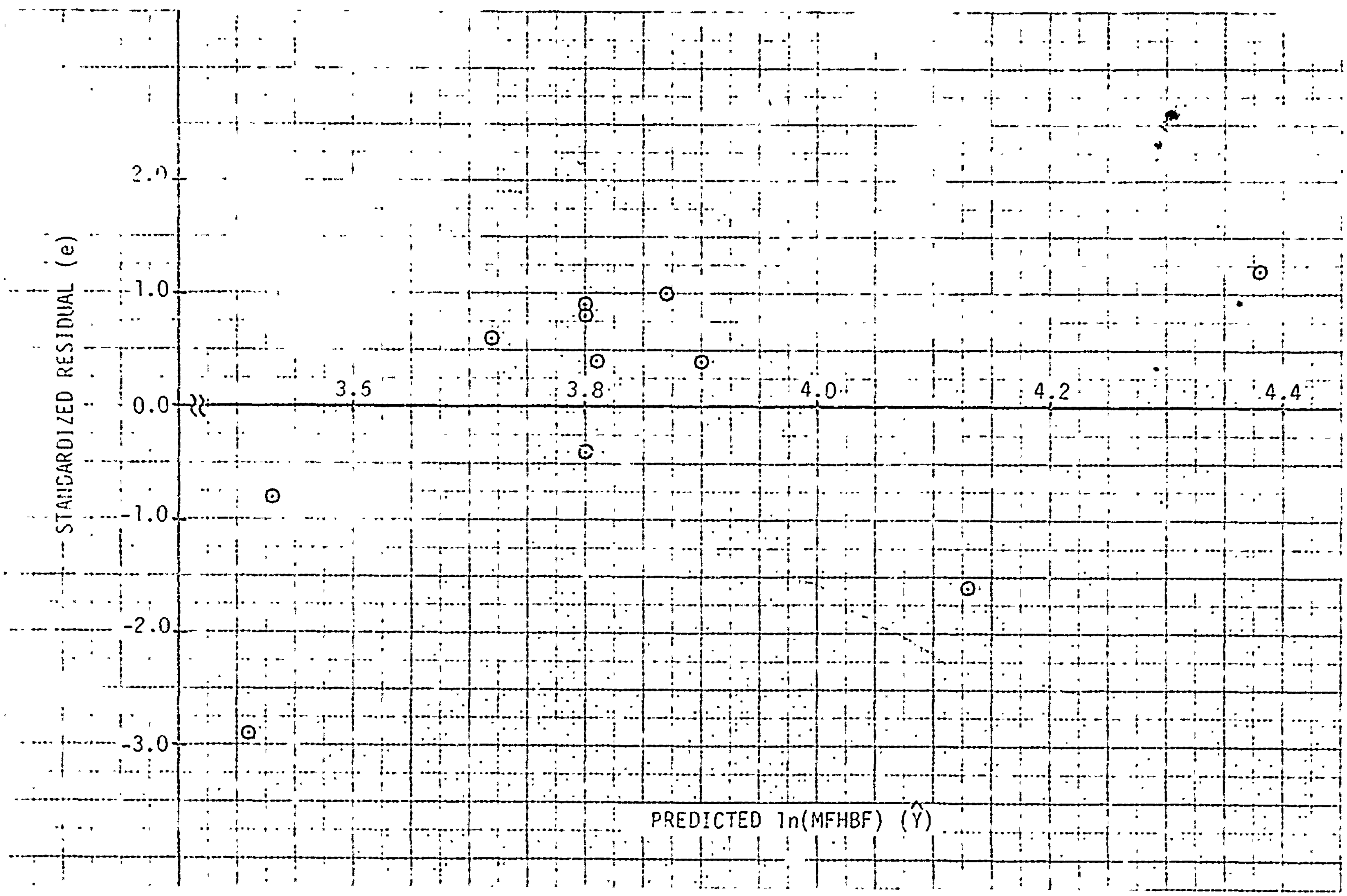


Figure 7-6 (Cont.). Predicted ln(MFHBF) vs Standardized Residuals For Rotary Wing Aircraft -- WUC 63000

in the plotted values was detected. Thus, the baseline MFHBF prediction equations were considered statistically adequate with respect to the form of the mathematical expressions.

The results of the "leave-one-out" validation procedure are presented in Tables 7-1 and 7-2. A comparison of the coefficients and statistics was made to determine the baseline MFHBF prediction equations' sensitivity to the data. None of the adjusted coefficients for WUC's 11000, 13000, 41000, and 63000 for fixed wing aircraft, and WUC's 13000 and 41000 for rotary wing aircraft appeared to deviate significantly from their baseline prediction equation coefficients.

While the remaining equations were not found to be sensitive to the data, some adjusted coefficients for WUC 27000 for fixed wing aircraft and WUC's 11000, 22000, and 63000 for rotary wing aircraft reflected a greater change. This was primarily due to the smaller number of aircraft used to derive these prediction equations. The omission of a single aircraft decreased the size of the data base between 9% and 14%. For these equations, only one set of adjusted coefficients, associated with the omission of an individual aircraft, varied considerably from the respective baseline coefficients. Thus, the relationship between the MFHBF of the two-digit WUC subsystem and the set of predictor variables reflected in the baseline prediction equation was felt to be stable.

The validation of the models revealed no significant shortcomings in the predictions made for the historical aircraft at the two-digit WUC level or at the aircraft level. Tables 7-3 through 7-8 present the results for three fixed wing and three rotary wing aircraft used in model development. In each case, predicted values were computed only for those WUC's applicable to the given aircraft. A prediction of the MFHBF for an aircraft consisting of the indicated two-digit WUC subsystems was obtained by mathematically combining the predicted MFHBF values for the subsystems. In all cases, this predicted value was close to the historical value. The overall aircraft prediction equation (WUC 00000), developed for use in validating notional aircraft predictions, also showed good predictive ability with historical aircraft.

TABLE 7-1. COMPARISON OF FIXED WING AIRCRAFT PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS AIRFRAME --- WUC 11000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	A-4E	KA-6D	KA-6D	C-2A
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Wing Span -- Folded	$.45925 \times 10^{-1}$	$.45120 \times 10^{-1}$	$.43332 \times 10^{-1}$	$.43332 \times 10^{-1}$	$.56323 \times 10^{-1}$
Max. A/C Length	$-.47705 \times 10^{-1}$	$-.46916 \times 10^{-1}$	$-.58990 \times 10^{-1}$	$-.58990 \times 10^{-1}$	$-.53286 \times 10^{-1}$
Fuselage Volume	$-.21737 \times 10^{-3}$	$-.21971 \times 10^{-3}$	$-.15925 \times 10^{-3}$	$-.15925 \times 10^{-3}$	$-.36964 \times 10^{-3}$
Flt. Control Surface Area	$-.28539 \times 10^{-3}$	$-.26932 \times 10^{-3}$	$-.25458 \times 10^{-4}$	$-.25458 \times 10^{-4}$	$-.63269 \times 10^{-4}$
Kinetic Energy	$-.44285 \times 10^{-3}$	$-.43253 \times 10^{-3}$	$-.92046 \times 10^{-3}$	$-.92046 \times 10^{-3}$	$-.78468 \times 10^{-4}$
Tot. Fuel Capacity	$.22795 \times 10^{-4}$	$.22403 \times 10^{-4}$	$.37803 \times 10^{-4}$	$.37803 \times 10^{-4}$	$.30611 \times 10^{-4}$
Max. Wing Loading	$-.80609 \times 10^{-2}$	$-.77746 \times 10^{-2}$	$-.10449 \times 10^{-1}$	$-.10449 \times 10^{-1}$	$-.96373 \times 10^{-2}$
Max. Thrust to Max. T.O. Wt.	1.00835	1.00272	1.18501	1.18501	1.25151
Flt. Design Wt. to Max. T.O. Wt.	$.42445 \times 10^{-1}$	$.90334 \times 10^{-1}$	$-.99733 \times 10^{-1}$	$-.99733 \times 10^{-1}$	.20353
Constant	3.90037	3.82140	4.49839	4.49839	3.76739
S^2	.0269	.0296	.0164	.0164	.0095
R^2 -- Least Squares	.762	.741	.833	.833	.780
R^2 -- Ridge	.735	.709	.816	.816	.754
	1.55349	1.56033	.98502	.98502	1.37784
	.30229	.31228	.24811	.24811	.28808

COMPARISON OF FIXED WING AIRCRAFT PREDICTION EQUATIONS
FOR SELECTED AIRCRAFT DELETIONS
LANDING GEAR -- WUC 13000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	E-2C	EA-3B	KA-3B	A-6A
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Max. A/C Length	$-.34022 \times 10^{-1}$	$-.31759 \times 10^{-1}$	$-.36106 \times 10^{-1}$	$-.36421 \times 10^{-1}$	$-.33399 \times 10^{-1}$
Max. A/C Height	$.57675 \times 10^{-1}$	$.58522 \times 10^{-1}$	$.70166 \times 10^{-1}$	$.44257 \times 10^{-1}$	$.56920 \times 10^{-1}$
Wheelbase	$-.22654 \times 10^{-1}$	$-.23338 \times 10^{-1}$	$-.17728 \times 10^{-1}$	$-.29570 \times 10^{-1}$	$-.22732 \times 10^{-1}$
Fuselage Volume	$-.24390 \times 10^{-3}$	$-.18257 \times 10^{-3}$	$-.22095 \times 10^{-3}$	$-.32611 \times 10^{-3}$	$-.24573 \times 10^{-3}$
Kinetic Energy	$-.18810 \times 10^{-2}$	$-.16147 \times 10^{-2}$	$-.24052 \times 10^{-2}$	$-.13546 \times 10^{-2}$	$-.18192 \times 10^{-2}$
Max. Ldg. Wt. -- Arr. or Design	$.36539 \times 10^{-4}$	$.30715 \times 10^{-4}$	$.37777 \times 10^{-4}$	$.41467 \times 10^{-4}$	$.35880 \times 10^{-4}$
Min. Combat Mission Time	-.12237	$-.76746 \times 10^{-1}$	-.12506	-.12752	-.12058
Type A or B	-.34138	$-.99227 \times 10^{-1}$	-.30120	-.39000	-.33936
(Min. Combat Mission Time) x (Type A or B)	$.10543 \times 10^{-1}$	$-.25787 \times 10^{-1}$	$.13694 \times 10^{-1}$	$.90461 \times 10^{-2}$	$.80203 \times 10^{-2}$
Constant	3.74917	3.42590	3.54903	4.13745	3.73932
k	.0145	.0193	.0151	.0117	.0152
R^2 -- Least Squares	.738	.713	.746	.827	.739
R^2 -- Ridge	.711	.678	.718	.811	.709
SSE	.80075	.80940	.71059	.52515	.80610
$\hat{\sigma}$	.21702	.22492	.21074	.18116	.22445

TABLE 7-1 (Cont.). COMPARISON OF FIXED WING AIRCRAFT PREDICTION EQUATIONS
FOR SELECTED AIRCRAFT DELETIONS
TURBOFAN ENGINES -- WUC 27000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	S-3A	AV-8A	A-7B	S-3A
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Wing Area	$.74634 \times 10^{-1}$	$.95363 \times 10^{-1}$	$.88705 \times 10^{-1}$	$.72378 \times 10^{-1}$	$.95363 \times 10^{-1}$
Spec. Fuel Consumption	29.39066	-32.32238	40.48830	11.37002	-32.32238
Max. Thrust to Instl. Eng. Wt.	.20384	2.94306	-1.32631	-.54635	2.94306
Min. Combat Mission Time	8.29340	9.97074	9.23867	7.20320	9.97074
Constant	-27.07110	-11.46661	-34.94115	-8.70205	-11.46661
k	.0000	.0000	.0049	.0000	.0000
R^2 -- Least Squares	.993	.992	.995	.997	.992
R^2 -- Ridge	.993	.992	.990	.997	.992
[illegible]	11.47225	5.45281	8.78382	4.50699	5.45281
[illegible]	2.39502	2.33513	2.96375	2.12297	2.33513

TABLE [illegible] (CONT.). COMPARISON OF FIXED WING AIRCRAFT
PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS
AIR COND/PRESSURIZATION/ICE CONTROL -- WUC 41000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	A-4M	C-2A	KA-3B	A-7[illegible]
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Crew Size -- Cockpit or Total	.20048	.16291	$.73803 \times 10^{-1}$	.14208	.19734
Pressurized Fuselage -- Volume	$-.23720 \times 10^{-3}$	$-.21683 \times 10^{-3}$	$.48624 \times 10^{-3}$	$-.23672 \times 10^{-3}$	$-.23108 \times 10^{-3}$
Avionics Weight Installed	$-.69055 \times 10^{-4}$	$-.52856 \times 10^{-4}$	$-.10570 \times 10^{-3}$	$-.37389 \times 10^{-4}$	$-.66803 \times 10^{-4}$
Total Generator Elec. Power	$.14571 \times 10^{-2}$	$.37460 \times 10^{-3}$	$.19700 \times 10^{-2}$	$.31669 \times 10^{-2}$	$.13200 \times 10^{-2}$
Total ECS Weight	$-.46927 \times 10^{-3}$	$-.24805 \times 10^{-3}$	$-.40896 \times 10^{-3}$	$-.47145 \times 10^{-3}$	$-.44550 \times 10^{-3}$
No. of Engines	-.54877	-.50034	-.27775	-.42923	-.54678
Empty Weight	$.73377 \times 10^{-6}$	$-.16618 \times 10^{-5}$	$-.12771 \times 10^{-4}$	$-.16227 \times 10^{-4}$	$.14779 \times 10^{-6}$
Max. Rate of Climb at Sea Level	$.71702 \times 10^{-4}$	$.49265 \times 10^{-4}$	$.59194 \times 10^{-4}$	$.68091 \times 10^{-4}$	$.70518 \times 10^{-4}$
Max. Speed -- Mach No.	-.37055	-.31130	-.35101	-.30458	-.36425
Constant	4.27794	4.34547	4.39724	4.36565	4.28912
k	.0462	.0616	.0670	.0575	.0501
R^2 -- Least Squares	.697	.633	.722	.752	.691
R^2 -- Ridge	.644	.593	.693	.727	.656
SSE	3.05421	2.94381	2.51659	2.43770	3.06810
$\hat{\sigma}$	.42386	.42894	.39660	.39033	.43790

TABLE 7-1 (Cont.). COMPARISON OF FIXED WING AIRCRAFT PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS UHF COMMUNICATION SYSTEM -- WUC 63000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	KC-130R	EA-3B	EA-6A	A-4M
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Crew Size -- Cockpit or Total	$-.69280\times10^{-1}$	$-.29410\times10^{-1}$	$-.71378\times10^{-1}$	$-.75471\times10^{-1}$	$-.73943\times10^{-1}$
Fuselage Volume	$.49928\times10^{-4}$	$.24925\times10^{-4}$	$.46198\times10^{-4}$	$.95238\times10^{-4}$	$.53893\times10^{-4}$
Avionics Weight Installed	$.19025\times10^{-4}$	$.14389\times10^{-4}$	$.19352\times10^{-4}$	$.27163\times10^{-4}$	$.21443\times10^{-4}$
Total ECS Weight	$.33068\times10^{-3}$	$.21890\times10^{-3}$	$.33494\times10^{-3}$	$.36191\times10^{-3}$	$.33747\times10^{-3}$
Kinetic Energy	$.87231\times10^{-3}$	$.10483\times10^{-3}$	$.63808\times10^{-3}$	$.14274\times10^{-2}$	$.87748\times10^{-3}$
Max. Wing Loading	$-.95668\times10^{-2}$	$-.70770\times10^{-2}$	$-.86709\times10^{-2}$	$-.21835\times10^{-1}$	$-.10426\times10^{-1}$
Max. Rate of Climb at Sea Level	$.94571\times10^{-4}$	$.83643\times10^{-4}$	$.84773\times10^{-4}$	$.15118\times10^{-3}$	$.10099\times10^{-3}$
Max. Service Ceiling	$-.93535\times10^{-5}$	$-.52866\times10^{-5}$	$-.72232\times10^{-5}$	$-.14908\times10^{-5}$	$-.97479\times10^{-5}$
Max. Combat Radius	$.25854\times10^{-3}$	$.22432\times10^{-3}$	$.33599\times10^{-3}$	$.31533\times10^{-3}$	$.26149\times10^{-3}$
Min. Combat Mission Time	$-.15570\times10^{-1}$	$.46520\times10^{-2}$	$.31059\times10^{-2}$	$-.48559\times10^{-2}$	$-.15554\times10^{-1}$
Max. Combat Mission Time	$.91245\times10^{-1}$	$.58420\times10^{-1}$	$.64111\times10^{-1}$	.10679	$.94317\times10^{-1}$
Constant	3.21447	3.00468	3.19593	3.29329	3.24308
k	.0467	.0618	.0485	.0247	.0443
R^2 -- Least Squares	.549	.418	.547	.693	.557
R^2 -- Ridge	.493	.352	.488	.654	.499
SSE	4.15252	4.10029	3.91752	2.67927	4.10061
$\hat{\sigma}$	.46749	.47727	.46652	.38581	.47729

TABLE 7-2. COMPARISON OF ROTARY WING AIRCRAFT PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS
AIRFRAME --- WUC 11000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	CH-46F	CH-53D	SH-3G	CH-46F
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
A/C Length --Operating	$-.50565 \times 10^{-1}$	$-.43609 \times 10^{-1}$	$-.50072 \times 10^{-1}$	$-.63088 \times 10^{-1}$	$-.43609 \times 10^{-1}$
Wheelbase	$-.38548 \times 10^{-1}$	$-.50311 \times 10^{-1}$	$.87347 \times 10^{-1}$	$.25198 \times 10^{-1}$	$-.50311 \times 10^{-1}$
Tot. SHP -- Mil. or Int. Pwr. to Max. T.O. Weight	-47.96398	-45.69258	-37.50637	-45.13633	-45.69258
Main Rotor Disc Area	$-.40014 \times 10^{-3}$	$-.36528 \times 10^{-3}$	$-.78124 \times 10^{-3}$	$-.33598 \times 10^{-3}$	$-.36528 \times 10^{-3}$
Total Fuel Capacity	$.21651 \times 10^{-4}$	$.17086 \times 10^{-4}$	$.19341 \times 10^{-3}$	$.13392 \times 10^{-5}$	$.17086 \times 10^{-4}$
Max. Speed at Sea Level	$.97494 \times 10^{-1}$	$.91967 \times 10^{-1}$	.10684	$.89267 \times 10^{-1}$	$.91967 \times 10^{-1}$
Constant	4.72218	4.81983	-.78566	4.86777	4.81983
$\hat{k}$	.0075	.0100	.0075	.0075	.0010
R^2 -- Least Squares	.883	.835	.931	.976	.835
R^2 -- Ridge	.853	.735	.878	.916	.763
SSE	.73171	.76520	.50700	.35569	.76520
$\hat{\sigma}$	.42770	.50504	.41110	.34433	.50504

TABLE 7-2 (Cont.). COMPARISON OF ROTARY WING AIRCRAFT PREDICTION EQUATIONS
FOR SELECTED AIRCRAFT DELETIONS
LANDING GEAR -- WUC 13000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	HH-46A	SH-3G	SH-3G	HH-3A
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Fuselage Length -- Folded	$-.20672\times10^{-1}$	$-.14711\times10^{-1}$	$-.19272\times10^{-1}$	$-.19272\times10^{-1}$	$-.15191\times10^{-1}$
Fuselage Depth -- Folded	-.23710	-.22430	-.23011	-.23011	-.24788
A/C Height -- Operating	$.43456\times10^{-1}$	$.33380\times10^{-1}$	$.40810\times10^{-1}$	$.40810\times10^{-1}$	$.31147\times10^{-1}$
Wheelbase	$.52188\times10^{-1}$	$.42887\times10^{-1}$	$.40784\times10^{-1}$	$.40784\times10^{-1}$	$.48944\times10^{-1}$
Main Gear Tread	$.21140\times10^{-1}$	$.24610\times10^{-1}$	$.52216\times10^{-1}$	$.52216\times10^{-1}$	$.30249\times10^{-1}$
Constant	3.21700	3.16339	3.03330	3.03330	3.21852
k	.0050	.0050	.0050	.0050	.0075
R^2 -- Least Squares	.941	.912	.973	.973	.938
R^2 -- Ridge	.883	.853	.906	.906	.874
SSE	.07889	.06550	.05072	.05072	.08021
$\hat{\sigma}$	.12562	.12795	.11261	.11261	.14160

TABLE [illegible] (Cont.). COMPARISON OF ROTARY WING AIRCRAFT PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS TURBOSHAFT ENGINES -- WUC 22000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	CH-46F	SH-2F	SH-2F	SH-3D
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Empty Weight	$.32996 \times 10^{-2}$	$.24315 \times 10^{-2}$	$.21300 \times 10^{-2}$	$.21300 \times 10^{-2}$	$.33203 \times 10^{-2}$
Military SHP per Engine	$-.38649 \times 10^{-1}$	$-.23817 \times 10^{-1}$	$-.33193 \times 10^{-1}$	$-.33193 \times 10^{-1}$	$-.38949 \times 10^{-1}$
Turbine Inlet Temp.	.22618	.18181	.19623	.19623	.22787
Max. Speed at Sea Level	.61042	.20823	.81186	.81186	.61090
Constant	-430.03961	-309.35370	-396.57370	-396.57370	-432.84482
$\hat{k}$	.0175	.0200	.0175	.0175	.0175
R^2 -- Least Squares	.965	.962	.956	.956	.967
R^2 -- Ridge	.873	.836	.841	.841	.876
SSE	210.67310	189.27292	208.61108	208.61103	206.78838
$\hat{\sigma}$	5.92555	6.15261	6.45927	6.45927	6.43099

TABLE 7-2 (Cont.). COMPARISON OF ROTARY WING AIRCRAFT PREDICTION EQUATIONS
FOR SELECTED AIRCRAFT DELETIONS
AIR COND/PRESSURIZATION/ICE CONTROL -- WUC 41000

Aircraft Deleted	- (Baseline Pred. Eq'n.)	CH-53DE	CH-46F	CH-46F	SH-3G
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Empty Weight	$.14056 \times 10^{-3}$	$.14678 \times 10^{-3}$	$.12422 \times 10^{-3}$	$.12422 \times 10^{-3}$	$.14726 \times 10^{-3}$
Total Generator Elec. Power	$-.26245 \times 10^{-1}$	$-.26822 \times 10^{-1}$	$-.24596 \times 10^{-1}$	$-.25696 \times 10^{-1}$	$-.26405 \times 10^{-1}$
Ver. Rate of Climb at S.L. -- Mil.	$.69758 \times 10^{-3}$	$.75413 \times 10^{-3}$	$.61525 \times 10^{-3}$	$.61525 \times 10^{-3}$	$.74114 \times 10^{-3}$
Max. Speed at Sea Level	$-.23598 \times 10^{-1}$	$-.25002 \times 10^{-1}$	$-.17581 \times 10^{-1}$	$-.17581 \times 10^{-1}$	$-.25136 \times 10^{-1}$
Constant	7.68804	7.79027	7.07793	7.07793	7.84384
k	.0075	.0070	.0100	.0100	.0059
R^2 -- Least Squares	.985	.984	.992	.992	.985
R^2 -- Ridge	.983	.982	.987	.987	.984
SSE	.03785	.03178	.01963	.01963	.03565
$\hat{\sigma}$	.09726	.10291	.08087	.08087	.10900

TABLE 7-2 (Cont.). COMPARISON OF ROTARY WING AIRCRAFT PREDICTION EQUATIONS FOR SELECTED AIRCRAFT DELETIONS UHF COMMUNICATION SYSTEM -- WUC 63000

Aircraft Deleted	- (Baseline Prec. Eq'n.)	SH-2F	SH-3G	SH-3G	HH-46A
Reason for Deletion	-	Max. MFHBF	Min. MFHBF	Max. Residual	Min. Residual
Predictor Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Crew Size -- Total	$.52142\times10^{-1}$	$.54818\times10^{-1}$	-.17526	-.17526	$.64785\times10^{-1}$
Avionics Weight Installed	$.26948\times10^{-3}$	$.21700\times10^{-3}$	$.13111\times10^{-3}$	$.13111\times10^{-3}$	$.26613\times10^{-3}$
Total ECS Weight	$.11000\times10^{-2}$	$.13490\times10^{-2}$	$-.34121\times10^{-3}$	$-.34121\times10^{-3}$	$.12037\times10^{-2}$
Ver. Rate of Climb at S.L. -- Mil.	$.43734\times10^{-3}$	$.30079\times10^{-3}$	$.20574\times10^{-3}$	$.20574\times10^{-3}$	$.43633\times10^{-3}$
Constant	2.74886	2.84240	4.26204	4.26204	2.69482
k	.0567	.1135	.0839	.0839	.0632
R^2 -- Least Squares	.826	.706	.913	.913	.834
R^2 -- Ridge	.810	.658	.908	.908	.813
SSE	.17571	.17735	.05015	.05015	.17061
$\hat{\sigma}$	.17111	.18833	.10015	.10015	.18472

TABLE 7-3. PREDICTION OF HISTORICAL FIXED WING AIRCRAFT RELIABILITY -- A-7E

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	1.042	1.042
2	11000	10.054	12.090
3	12000	39.365	35.920
4	13000	12.955	10.900
5	14000	20.422	24.570
6	27000	37.840	35.910
7	29000	50.645	42.090
8	41000	65.569	50.790
9	42000	16.275	24.380
10	44000	20.193	21.170
11	45000	34.616	33.640
12	46000	32.622	42.790
13	47000	80.797	116.570
14	49000	106.567	145.630
15	51000	18.948	15.220
16	56000	67.069	363.870
17	57000	52.956	22.760
18	63000	38.278	19.320
19	64000	154.050	564.570
20	65000	89.667	83.490
21	66000	1533.576	3033.700
22	67000	97.200	381.510
23	71000	61.538	25.960
24	72000	26.658	46.610
25	73000	16.305	6.230
26	74000	46.743	53.080
27	75000	35.848	23.600
28	76000	60.636	50.220
29	91000	255.093	235.100
30	96000	3017.173	4127.820
31	97000	2969.561	2962.320
	AIRCRAFT	1.203	1.043

TABLE 7-4. PREDICTION OF HISTORICAL FIXED WING AIRCRAFT RELIABILITY -- RF-8G

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	.795	.807
2	11000	9.269	10.300
3	12000	26.308	35.360
4	13000	8.771	7.620
5	14000	19.700	13.790
6	23000	27.233	22.630
7	29000	35.636	27.140
8	41000	38.979	28.310
9	42000	13.906	8.000
10	44000	19.388	24.170
11	45000	22.049	17.570
12	46000	27.711	28.710
13	47000	87.696	72.390
14	49000	106.116	83.220
15	51000	15.460	9.270
16	56000	80.058	113.920
17	57000	22.927	12.610
18	63000	22.445	21.250
19	65000	71.440	36.380
20	66000	701.169	523.500
21	67000	121.674	251.760
22	71000	27.149	16.070
23	72000	38.442	28.250
24	73000	89.792	159.750
25	76000	38.453	33.090
26	77000	7.433	10.810
27	91000	169.673	201.420
28	97000	2696.127	1387.200
	AIRCRAFT	.946	.808

TABLE 7-5. PREDICTION OF HISTORICAL FIXED WING AIRCRAFT RELIABILITY -- S-3A

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	1.201	1.134
2	11000	10.341	12.960
3	12000	59.646	79.140
4	13000	15.736	15.880
5	14000	23.528	27.920
6	24000	69.353	69.550
7	27000	36.734	36.640
8	29000	32.129	41.020
9	41000	31.530	44.280
10	42000	24.808	31.420
11	44000	22.917	21.090
12	45000	51.893	70.270
13	46000	56.486	78.700
14	47000	187.158	186.590
15	49000	66.392	62.880
16	51000	17.301	26.400
17	56000	66.398	96.120
18	57000	54.442	35.940
19	61000	92.460	103.910
20	63000	46.965	74.440
21	64000	55.553	21.810
22	65000	75.118	65.630
23	66000	1134.577	1144.720
24	67000	146.098	242.450
25	69000	124.915	301.300
26	71000	30.969	52.360
27	72000	19.710	21.280
28	73000	27.280	5.120
29	74000	1602.318	1153.470
30	75000	182.232	143.460
31	76000	5.567	128.020
32	91000	159.600	153.900
33	96000	657.263	1010.570
34	97000	2109.258	1283.080
	AIRCRAFT	1.053	1.165

TABLE 7-6. PREDICTION OF HISTORICAL ROTARY WING AIRCRAFT RELIABILITY -- CH-53D

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	.791	.760
2	11000	4.473	4.390
3	12000	22.304	20.850
4	13000	12.731	11.680
5	14000	10.248	8.970
6	15000	6.035	5.910
7	22000	28.503	27.790
8	24000	52.201	46.540
9	26000	11.781	11.490
10	29000	10.734	10.450
11	41000	413.588	402.550
12	42000	11.459	11.580
13	44000	14.873	15.280
14	45000	41.334	43.920
15	46000	48.991	50.750
16	49000	126.823	90.140
17	51000	21.157	20.130
18	56000	73.198	60.090
19	57000	16.159	15.580
20	61000	54.118	52.750
21	62000	63.503	63.110
22	63000	62.055	50.140
23	64000	65.337	53.920
24	65000	68.764	99.670
25	67000	452.591	380.390
26	71000	25.932	23.980
27	72000	107.900	101.630
28	75000	1152.971	1247.860
29	76000	752.639	760.290
30	91000	784.813	702.760
31	96000	554.350	658.140
	AIRCRAFT	.763	.734

TABLE 7-7. PREDICTION OF HISTORICAL ROTARY WING AIRCRAFT RELIABILITY -- HH-46A

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	.871	.864
2	11000	4.974	4.820
3	12000	27.327	25.040
4	13000	18.019	19.920
5	14000	15.683	15.810
6	15000	6.410	6.290
7	22000	17.554	16.900
8	24000	57.794	57.730
9	26000	14.545	16.230
10	29000	24.638	22.450
11	41000	140.455	143.270
12	42000	15.832	13.450
13	44000	18.267	17.350
14	45000	21.914	16.860
15	46000	78.215	62.330
16	49000	104.498	237.950
17	51000	17.567	14.510
18	56000	227.913	233.100
19	57000	26.109	21.110
20	61000	417.391	428.020
21	62000	374.121	380.060
22	63000	44.834	42.620
23	64000	48.756	40.540
24	65000	183.227	260.610
25	71000	29.523	27.980
26	72000	76.086	69.630
27	91000	477.562	314.530
28	96000	344.936	354.100
29	97000	1942.371	2104.920
	AIRCRAFT	.913	.866

TABLE 7-8. PREDICTION OF HISTORICAL ROTARY WING AIRCRAFT RELIABILITY -- SH-3A

NO.	WUC	PREDICTED MFHBF	HISTORICAL MFHBF
1	00000	.857	.851
2	11000	4.816	5.260
3	12000	37.170	39.410
4	13000	10.382	10.130
5	14000	36.322	40.140
6	15000	9.163	9.860
7	22000	15.229	16.310
8	26000	18.102	19.710
9	29000	24.298	30.820
10	41000	267.757	281.170
11	42000	13.150	16.450
12	44000	19.417	20.890
13	45000	21.637	22.900
14	46000	74.433	65.910
15	49000	33.801	38.180
16	51000	24.659	23.480
17	54000	310.825	318.330
18	56000	131.679	128.350
19	57000	19.758	17.280
20	61000	124.171	138.360
21	62000	121.761	119.860
22	63000	41.173	45.060
23	64000	38.634	35.540
24	65000	168.233	163.940
25	67000	486.570	452.440
26	71000	27.963	27.670
27	72000	31.690	39.250
28	73000	17.849	7.660
29	74000	118.522	118.240
30	75000	118.538	114.090
31	91000	319.621	209.240
32	97000	1848.547	1773.550
	AIRCRAFT	.854	.846

For most two-digit WUC's of a given aircraft, the predicted MFHBF were in reasonable agreement with the historical values. Those two-digit WUC predictions which differed considerably from the historical values were for WUC subsystems having large values for the MFHBF. Thus, the impact on the overall MFHBF of the aircraft was minimal.

The validation of the models' predictive ability for notional aircraft, performed by NAVAIR, led to some changes in the baseline MFHBF prediction equations of the two models. A comparison between the predicted baseline MFHBF values obtained from the equation and the NAVAIR baseline for the SBAMS aircraft estimates showed reasonable agreement, within expected uncertainty, for most two-digit WUC subsystems. Those predicted values found to differ significantly from the NAVAIR estimates, which incorporated the 3-M MFHBF values for the F-14A, A-6E, S-3A, E-2C, C-1A, C-2A, KA-6D, and AV-8A, were the result of extrapolating beyond the range of values of historical aircraft characteristics. As the ability to extrapolate was crucial to the use of the model with notional aircraft, various equations were adjusted.

To improve the ability to predict with extrapolated data, alternative equations were chosen for those two-digit WUC subsystems with unreasonable predicted values. In some cases, alternative equations identified during the refinement phase of model development were used by NAVAIR to arrive at more reasonable baseline MFHBF predicted values. In the remaining situations, predictor variables causing the extrapolation were replaced with other variables to form an equation with reasonable predictive ability for notional aircraft. Through the substitution of equations or predictor variables, the adverse effects of the extrapolation were minimized, and the final Baseline MFHBF Prediction Models were formed.

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TABLE A-1. MINIMUM AND MAXIMUM MFHBF VS TWO-DIGIT WUC FOR FIXED WING AIRCRAFT

WUC	MFHBF JULY 76 -- JUNE 78 MIN	MAX	JULY 78 -- JUNE 79 MIN	MAX
00000	0.39	2.42	0.41	1.50
11000	4.68	21.70	3.20	15.31
12000	17.62	205.11	19.17	198.13
13000	5.30	19.37	5.35	20.65
14000	8.78	66.61	8.52	32.94
20000	15.72	73.28	14.41	64.08
22000	14.84	59.86	13.96	242.36
23000	20.10	56.44	20.92	64.08
24000	62.46	73.07	73.75	181.76
27000	15.72	73.28	14.41	53.86
29000	12.73	135.70	10.24	146.10
41000	11.57	137.88	13.98	124.57
42000	5.04	31.42	6.18	27.17
44000	8.83	36.51	9.26	28.35
45000	9.79	119.19	10.10	127.30
46000	9.76	85.10	8.37	101.99
47000	20.46	186.59	12.45	178.69
49000	19.11	298.99	12.87	208.81
51000	7.73	47.08	10.16	34.89
56000	14.97	363.87	13.21	392.53
57000	12.61	127.59	13.00	139.50
58000	51.83	9187.33	-	-
61000	18.59	122.15	20.12	138.68
62000	30.96	5211.05	26.32	3809.75
63000	16.58	130.40	14.09	136.32
64000	19.86	1216.50	15.99	1209.38
65000	29.38	217.50	28.95	331.86
66000	182.42	3033.70	270.20	2984.50
67000	5.22	1132.91	5.48	986.24
69000	5.51	301.30	23.69	672.67
71000	10.94	288.89	12.18	172.77
72000	2.69	121.99	2.66	126.02
73000	2.72	159.79	2.77	506.33
74000	2.52	1153.47	2.85	777.65
75000	19.54	156.71	18.81	263.91
76000	2.32	198.43	2.31	306.88
77000	2.19	5014.29	2.99	9849.00
91000	36.64	588.20	35.13	626.86
93000	81.43	283.35	54.25	243.91
96000	201.74	4127.82	240.08	5651.67
97000	269.00	6680.67	395.07	6091.69

TABLE A-2. MINIMUM AND MAXIMUM MFHBF VS TWO-DIGIT WUC FOR ROTARY WING AIRCRAFT

	MFHBF			
	JULY 76 -- JUNE 78		JULY 78 -- JUNE 79	
WUC	MIN	MAX	MIN	MAX
00000	0.76	0.98	0.58	0.93
11000	4.39	6.52	2.31	5.77
12000	20.85	44.83	19.77	43.23
13000	8.91	19.92	7.14	19.16
14000	8.97	46.31	8.61	45.50
15000	5.91	11.47	5.06	11.20
22000	10.54	30.17	10.85	33.94
24000	46.54	65.37	53.27	108.33
26000	9.28	19.84	9.06	18.50
29000	10.45	30.82	8.49	28.99
41000	103.29	402.55	104.68	606.95
42000	11.42	19.74	6.64	16.39
44000	14.14	21.23	12.56	28.21
45000	16.86	84.15	14.00	101.26
46000	12.52	128.72	18.52	157.31
49000	25.94	320.95	17.47	331.94
51000	14.51	35.80	14.63	45.35
54000	108.58	318.33	108.10	629.13
56000	57.85	238.86	53.27	143.19
57000	13.80	48.31	13.54	52.06
61000	52.75	428.02	64.72	468.39
62000	63.11	380.06	52.47	1521.38
63000	25.83	85.23	22.44	72.72
64000	29.61	101.20	24.91	111.33
65000	27.20	260.61	28.07	158.79
67000	380.39	1020.92	267.35	708.59
71000	20.67	45.34	21.54	46.32
72000	23.40	108.99	20.65	94.97
73000	6.62	51.03	7.11	88.89
74000	81.58	137.37	70.29	123.70
75000	75.31	5322.86	39.68	3360.00
76000	310.51	3568.00	247.40	2404.17
91000	209.24	1021.10	91.59	857.07
96000	354.10	1579.40	400.45	5412.00
97000	758.53	10523.75	882.46	4263.00

TABLE A-3. TYPICAL FORMAT OF STANDARD AIRCRAFT CHARACTERISTICS CHART

Standard Aircraft Characteristics

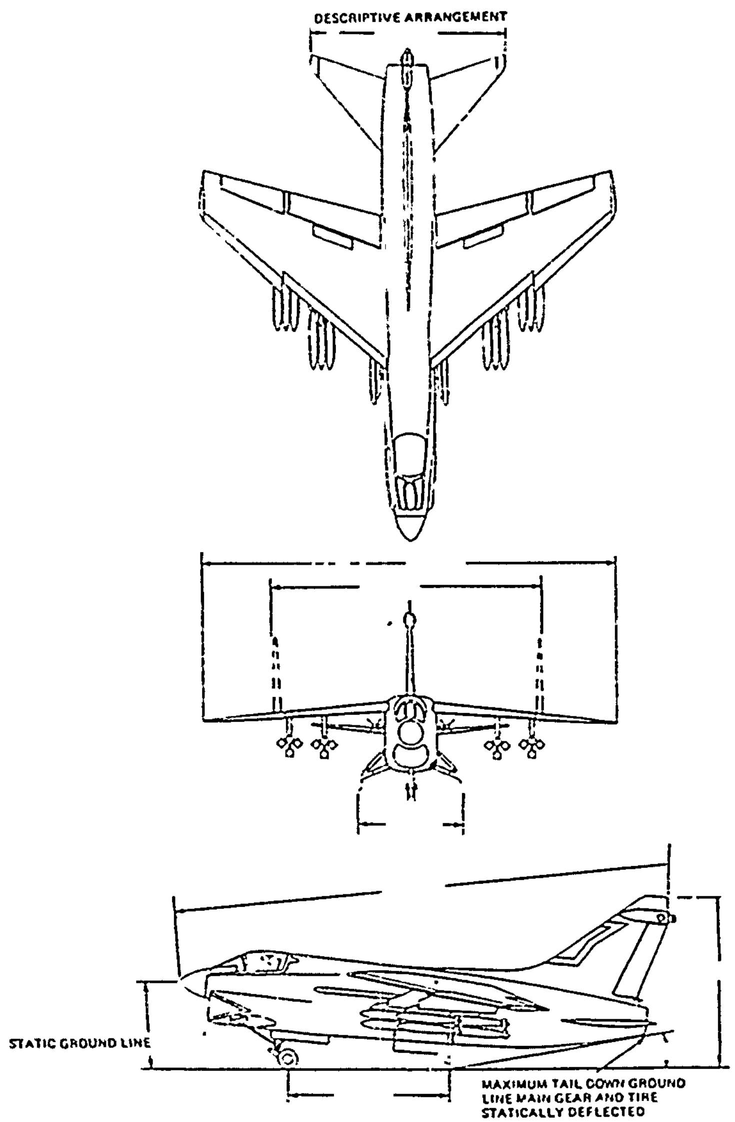
NAVY MODEL

AIRCRAFT

This Manual Supersedes
Which Should Be Destroyed In Accordance With
Applicable Security Regulations

PUBLISHED BY DIRECTION OF THE
COMMANDER OF THE NAVAL AIR SYSTEMS COMMAND

TABLE A-3 (CONT.). TYPICAL FORMAT OF STANDARD AIRCRAFT CHARACTERISTICS CHART



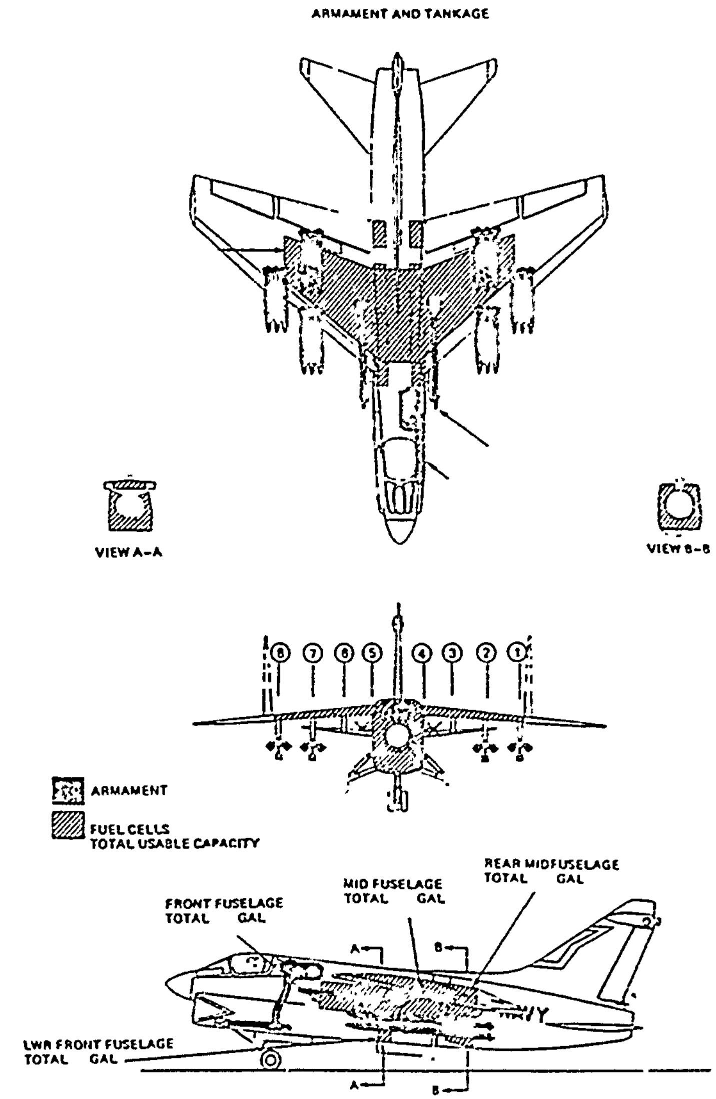


TABLE A-3 (CONT.). TYPICAL FORMAT OF STANDARD AIRCRAFT CHARACTERISTICS CHART

ELECTRONICS

Communications
Heading Mode System
Data Link
UHF Radio Receiver-

UHF ADF
UHF Receiver
Doppler Radar System
Radar Beacon
2-Inch Remote Attitude
IND System
Air Data Computer
IFF Transponder
TACAN

Intercom
Automatic Fight Control
System
Roll/Pitch Trim System
Nose Gear Steering
System
Approach Power
Compensating System
Angle-of-Attack System
Head-Up Display

Electrical Fusing System
Armament Monitor
and Control

Radar Altimeter

Armament Stations
Control Unit

Projected Map Display Set
AAU-19 Servoed Altimeter

MISSION AND DESCRIPTION

The is a single-place, carrier-based, , light attack airplane developed from the The airplane is designed to provide high attack utility and flexibility for close support and interdiction missions by virtue of a large number of external store stations to provide ordnance loading capacity and freedom of ordnance choice.

The has fixed wing incidence and a high-lift system composed of leading edge flaps and single slotted trailing edge flaps. Lateral control is provided by outboard ailerons and inboard spoiler. A stick steering autopilot is provided to augment the weapon system capability. An approach power compensator provides automatic speed control for carrier landing.

DEVELOPMENT

Contract Award ....
First Flight...................
First Deliveries...............

POWER PLANT

Engine.........................
Type...........................
Manufacturer...................
Length.........................
Diameter.......................
Specification..................
Compressor and Fan.............
Tail Pipe Nozzle...............

Specification Thrust Ratings
(Sea Level Static)

Intermediate...................
(Minute Limit)
Max. Continuous................

DIMENSIONS

Wing:
Area...........................
Span: Maximum..............
Folded..............
Aspect Ratio...............
Sweep 1/4 Chord............
MGC........................
Length.........................
Height.........................
Maximum Tread..................

WEIGHTS

Loading	Pounds	Limit Load Factor
Empty..............		....
Basic..............		....
Design.............		....
Combat (Clean A/C).		....
Max T.O. (Overload)		....
Max T.O. (Normal)..		....
Max Ldg (Carrier)..		....

*Not in Landing Configuration

FUEL AND OIL

Gal	No Tanks	Location	Self-Sealing

Usable Fuel Capacity............
Fuel Specification..............
Fuel Grade......................
OIL
Engine Oil Tank (total)
(useable)
Oil Specification..........

ORDNANCE

TABLE A-3 (CONT.). TYPICAL FORMAT OF STANDARD AIRCRAFT CHARACTERISTICS CHART

PERFORMANCE SUMMARY

TAKE-OFF LOADING CONDITION		(1) HI-HI-HI Mission Clean Airplane [10]	(2) Primary Attack Mission	(3) Primary Attack Mission	(4) Loiter Mission	(5) Deep Strike Mission	(6) Ferry Mission
TAKE-OFF WEIGHT	lb.						
Fuel internal/external (JP-5)	lb./lb						
Payload [1]	lb						
Wing loading	lb./sq. ft.						
Stall speed—power off/take-off power (40° Flaps)	kn.						
Take-off run at S.L.— calm/25 kn.wind [2]	ft.						
Take-off to clear 50 ft.— calm/25 kn wind [2]	ft.						
Max. effort take-off — calm [2]	ft.						
Max. speed/altitude	kn./ft.						
Rate of climb at S.L	fpm						
Time: S.L. to 20,000 ft [3]	min.						
Time: S.L. to 30,000 ft. [3]	min.						
Service ceiling (100 fpm)	ft.						
Combat range	n.mi.						
Average cruising speed	kn.						
Cruising altitude(s)	ft.						
Combat radius/mission time [4]	n.mi./hr.						
Average cruising speed	kn.						
COMBAT LOADING CONDITION		(7) HI-HI-HI Mission Clean Airplane	(8) Bombs Retained	(9) Bombs Retained	(10) Bombs Retained	(11) Bombs Retained	(12) Ferry Mission
COMBAT WEIGHT	lb.						
Engine power							
Fuel	lb.						
Combat speed/combat altitude	kn./ft.						
Rate of climb/combat altitude	fpm/ft.						
Combat ceiling (500 fpm)	ft.						
Rate of climb at S.L.	fpm.						
Max. speed at S.L.	kn.						
Max. Speed/altitude	kn./ft.						
LANDING WEIGHT [6]	lb.						
Fuel	lb.						
Stall speed—power-off/approach power	kn./kn.						
Landing distance-groundroll/over 50 ft. obst [8]	ft./ft.						

BASED ON FLIGHT TEST DRAG, AND ENGINE SPEC FUEL FLOW + %

NOTES

[1] PAYLOAD IS DROPPABLE ORDNANCE. DOES NOT INCLUDE ROUNDS OF AMMUNITION OR EXTERNAL FUEL TANKS.

[2] THRUST.

[3] CLIMB TIMES CONSIDER WEIGHT REDUCTION DUE TO FUEL USED.

[4] MISSION TIME EXCLUDES TIME FOR ENGINE START, TAKEOFF, ACCEL TO CLIMB SPEED AND. MINUTES LOITER AT SEA LEVEL.

[5] COMBAT WEIGHT EQUALS TAKE-OFF WEIGHT LESS % INITIAL FUEL.

[6] ROUNDS OF AMMUNITION RETAINED.

[7] RDS OF AMMO PLUS EXTERNAL FUEL TANKS RETAINED.

[8] ANTI-SKID BRAKING, ° FLAP

[9] ALL PYLONS CARRIED ALL THE TIME.

[10] CLEAN A/C - NO PYLONS OR RACKS ON WINGS OR FUSELAGE.

TABLE A-4. TYPICAL FORMAT OF GROUP WEIGHT STATEMENT

MIL-STD-1374A PART 1 GROUP WEIGHT STATEMENT PAGE 1
NAME WEIGHT EMPTY(STRUCTURE) MODEL
DATE REPORT

1	WING GROUP						
2	BASIC STRUCTURE-CENTER						
3	-INTERMEDIATE PANEL						
4	-OUTER PANEL						
5	-GLOVE						
6	SECONDARY STRUCTURE(INCL.WING FOLD WEIGHT LBS.)						
7	AILERONS(INCL.BALANCE WEIGHT LBS.)						
8	FLAPS-TRAILING EDGE						
9	-LEADING EDGE						
10	SLATS						
11	SPOILERS						
12							
13							
14	ROTOR GROUP						
15	BLADE ASSEMBLY						
16	HUB,HINGE(INCL. BLADE FOLD WEIGHT LBS.)						
17							
18							
19	TAIL GROUP						
20	STRUCT.-STABILIZER(INC. LBS.SEC STRUCT.)						
21	-FIN-INCL.DORSAL(INCL. LBS.SEC.STRUCT.)						
22	VENTRAL						
23	ELEVATOR(INCL.BALANCE WEIGHT LBS.)						
24	RUDDERS(INCL.BALANCE WEIGHT LBS.)						
25	TAIL ROTOR-BLADES						
26	-HUB,HINGE						
27							
28	BODY GROUP						
29	BASIC STRUCTURE-FUSELAGE OR HULL						
30	-BOOMS						
31	SECONDARY STRUCTURE-FUSELAGE OR HULL						
32	-BOOMS						
33	-SPEEDBRAKES						
34	-DOORS,RAMPS,PANELS,+MISC.						
35							
36							
37	ALIGHTING GEAR GROUP-TYPE**						
38	LOCATION		RUNNING*	STRUCT.	CONTROLS		
39	MAIN						
40	NOSE/TAIL						
41	ARRESTING GEAR						
42	CATAPULTING GEAR						
43							
44							
45	ENGINE SECTION OR NACELLE GROUP						
46	BODY-INTERNAL						
47	-EXTERNAL						
48	WING-INBOARD						
49	-OUTBOARD						
50							
51	AIR INDUCTION GROUP						
52	-DUCTS						
53	-RAMPS,PLUGS,SPIKES						
54	-DOORS,PANELS + MISC.						
55							
56							
57	TOTAL STRUCTURE						

*CHANGE TO FLOATS AND STRUTS FOR WATER TYPE GEAR
**LANDING GEAR -TYPE-, INSERT -TRICYCLE-,-TAIL WHEEL-,BICYCLE-,QUADRICYCLE OR SIMILAR DESCRIPTIVE NOMENCLATURE.

TABLE A-4 (CONT.). TYPICAL FORMAT OF GROUP WEIGHT STATEMENT

MIL-STD-1374A PART I — GROUP WEIGHT STATEMENT — PAGE 2
NAME — WEIGHT EMPTY(SYSTEMS) — MODEL
DATE — REPORT

1 PROPULSION GROUP			AUXILIARY		MAIN	
2 ENGINE INSTALLATION						
3						
4						
5 ACCESSORY GEAR BOXES+DRIVE						
6 EXHAUST SYSTEM						
7 ENGINE COOLING						
8 WATER INJECTION						
9 ENGINE CONTROL						
10 STARTING SYSTEM						
11 PROPELLER INSTALLATION						
12 SMOKE ABATEMENT						
13 LUBRICATION SYSTEM						
14 FUEL SYSTEM						
15 TANKS-PROTECTED						
16 -UNPROTECTED						
17 PLUMBING,ETC.						
18						
19 DRIVE SYSTEM						
20 GEAR BOXES,LUB SY+ROTOR BRK						
21 TRANSMISSION DRIVE						
22 ROTOR SHAFTS						
23						
24 FLIGHT CONTROLS GROUP						
25 COCKPIT CONTROLS(AUTOPILOT		LBS.)				
26 SYSTEMS CONTROLS						
27						
28						
29 AUXILIARY POWER PLANT GROUP						
30 INSTRUMENTS GROUP						
31 HYDRAULIC+PNEUMATIC GROUP						
32						
33 ELECTRICAL GROUP						
34						
35 AVIONICS GROUP						
36 EQUIPMENT						
37 INSTALLATION						
38						
39 ARMAMENT GROUP(INCL.PASSIVE PROT.			LBS.)			
40 FURNISHINGS+ EQUIPMENT GROUP						
41 ACCOMMODATIONS FOR PERSONNEL						
42 MISCELLANEOUS EQUIPMENT						
43 FURNISHINGS						
44 EMERGENCY EQUIPMENT						
45						
46 AIR CONDITIONING GROUP						
47 ANTI ICING GROUP						
48						
49 PHOTOGRAPHIC GROUP						
50 LOAD+HANDLING GROUP						
51 AIRCRAFT HANDLING						
52 LOAD HANDLING						
53 BALLAST						
54 MANUFACTURING VARIATION						
55 TOTAL CONTRACTOR CONTROLED						
56 TOTAL GFAE						
57 TOTAL WEIGHT EMPTY-PG2-3						

TABLE A-4 (CONT.). TYPICAL FORMAT OF GROUP WEIGHT STATEMENT

MIL-STD-1374A PART I — GROUP WEIGHT STATEMENT — PAGE 3

NAME — USEFUL LOAD AND GROSS WEIGHT — MODEL

DATE — REPORT

1 LOAD CONDITION						
2						
3 CREW (NO.)						
4 PASSENGERS (NO.)						
5 FUEL LOCATION TYPE	GALS.					
6 UNUSABLE						
7 INTERNAL						
8						
9						
10						
11 EXTERNAL						
12						
13						
14 OIL						
15 TRAPPED						
16 ENGINE						
17						
18 FUEL TANKS (LOCATION)						
19 WATER INJECTION FLUID (	GALS.)					
20						
21 BAGGAGE						
22 CARGO						
23						
24 GUN INSTALLATIONS						
25 GUNS LOCAT. FIX OR FLEX.	QUANTITY	CALIBER				
26 FUS.						
27 WING						
28 AMMO FUS.						
29 WING						
30						
31 SUPPORTS*						
32 WEAPONS INSTALLATION**						
33 RACKS, PYLONS, LAUNCHERS						
34 MISC.						
35 WEAPONS-BOMBS						
36 -MISSILES						
37						
38						
39						
40						
41						
42						
43						
44						
45						
46						
47						
48 SURVIVAL KITS						
49 LIFE RAFTS						
50 OXYGEN						
51 MISC.						
52						
53						
54						
55 TOTAL USEFUL LOAD						
56 WEIGHT EMPTY						
57 GROSS WEIGHT						

TABLE A-4 (CONT.). TYPICAL FORMAT OF GROUP WEIGHT STATEMENT

MIL-STD-1374A PART I — GROUP WEIGHT STATEMENT — PAGE 4
NAME — DIMENSIONAL AND STRUCTURAL DATA — MODEL
DATE — REPORT

1 WING ROTOR + TAIL GROUPS	WING	H TAIL	V TAIL	CANARD	ROTOR(BLADS/RTR)	
2						
3 RADIUS OR SPAN(FT)						
4 *SPAN AT .25 CHORD						
5 **ROOT CHORD(IN) -THEO.						
6 -MAX THICKNESS						
7 **PLANFORM BREAK-CHORD(IN)						
8 -MAX THICKNESS						
9 **TIP CHORD(IN) -THEO						
10 -MAX THICKNESS						
11 SWEEP ANGLE AT .25 CHORD						
12 ASPECT RATIO						
13 TAPER RATIO						
14 MEAN AERODYNAMIC CHORD						
15 AREAS***						
16						
17 AREAS WING	SPD.BRK.	L E FLAP	T E FLAP	SLATS	SPOILERS	AIL
18 (SQ.FT.PER AIRCRAFT						
19 FUS.	SPD.BRK.	ELEV	RUDDER	DORSAL		
20						
21						
22 ROTOR DISK AREAS -FWD		AFT		FOLDED WING SPAN		
23 WING .25MAC TO H TAIL .25MAC(IN)			NOSE	TO WING	.25 MAC	
24 WING .25MAC TO V TAIL .25MAC(IN)					LEMAC	
25 WING BOX,SPAN AT FUS.INTERSECT.			WING BOX	LENGTH	AT C.L.	
26						
27	CAPTURE	BLOW-IN	DUCT	MAX.DES.	CIRCUM-	
28 ENGINE INLETS	AREA	AREA	LENGTH	PRESSURE	FERENCE	
29 -MAIN						
30 -AUXILIARY						
31	LENGTH	DEPTH	WIDTH	WET.AREA	VOLUME	VOL.PRES
32 BODY + NACELLE GROUPS	FEET	FEET	FEET	SQ.FT.	CU.FT.	CU.FT.
33 FUSELAGE OR HULL****						
34 BOOMS						
35 NACELLES(INBD.B.L.)						
36 (OUTBD.B.L.)						
37 ALIGHTING GEAR GROUP	LENGTH-OLEO EXT.		OLEO TRAVEL		LENGTH ARREST	
38	AXLE-CL	TRUNNION	EXT.TO	COLLAPSED	HOOK TRUNNION	
39 -LOCATION	FORE	AFT	FORE	AFT	TO POINT	
40 -DIMENSION(IN)						
41						
42 PROPULSION GROUP (S.L.S.	UNINSTALLED THRUST IN LBS./ENGINE)					
43		MAXIMUM	INTERMEDIATE		MAX SLS	RPM,
44 ENGINES		RATING	RATING		SHAFT HP	MAX HP
45 MAIN(NO.)						
46 AUXILIARY(NO.)						
47						
48			OUTPUT	INTER	NUMBER	
49 ROTOR DRIVE SYSTEM	DESIGN	INPUT	RPM AT	ROTOR	GEAR	TORQUE
50	H.P.	R.P.M.	ROTOR	R.P.M.	BOXES	FACTOR
51 1/2 HOUR RATINGS -MAIN						
52 -TAIL						
53 -INTERMEDIATE						
54 CONT.RATINGS -MAIN						
55 -TAIL						
56 -INTERMEDIATE						
57						

TABLE A-4 (CONT.). TYPICAL FORMAT OF GROUP WEIGHT STATEMENT

MIL-STD-1374A PART I — GROUP WEIGHT STATEMENT — PAGE 5
NAME — DIMENSIONAL AND STRUCTURAL DATA — MODEL
DATE — (CONTINUED) — REPORT

1	FUEL SYSTEM	X PROTECTED XX		UNPROTECTED XX		INTEGRAL X,	
2	-INTERNAL* LOCATION	NO.TANKS	GALLONS	NO.TANKS	GALLONS	NO.TANKS	GALLONS
3	WING						
4	FUSELAGE						
5							
6	-EXTERNAL*						
7							
8	OIL						
9							
10							
11		QUANTITY X	GENERATOR	X	BATTERY	RATING	EMERG
12		MAIN X	OUTPUT	X	(TYPE	)	GENERATR
13	ELECTRICAL GENERATION	GENRATRS X	D.C.	A.C. X	AMP-HOURS		(KVA)
14	SYSTEMS						
15							
16							
17		BODY					
18		PLUS INT	EXTERNAL	FUEL IN		DESIGN	ULTIMATE
19		CONTENTS	WEIGHT	WINGS		GROSS	LOAD
20	STRUCTURAL DATA CONDITION	-LBS.	ON BODY	-LBS.		WEIGHT	FACTOR
21	FLIGHT-MANEUVER						
22	-GUST						
23	LANDING						
24	MAXIMUM GROSS WEIGHT WITH ZERO WING FUEL						
25	CATAPULTING						
26							
27	CRASH LIMIT LOAD FACTOR	-AXIAL		LATERAL		VERTICAL	
28	ULTIMATE LANDING SINK SPEED(FT/SEC)						
29	WING OR ROTOR LIFT ASSUMED FOR LONG DSGN COND.						
30	STALL SPEED LONG.CONFIGURATION-POWER OFF(KNOTS)						
31	APPROACH SPEED POWER ON(V-P KNOTS)						
32	ENGAGING SPEED(KNOTS)						
33	PRESSURIZED CABIN -ULTIMAT DESIGN						
34	PRESSURE DIFFERENTIAL-FLIGHT(PSI)						
35	CARGO FLOOR AREA(DESIGN LOAD			LBS/SQ.FT.)			
36	HYDRAULIC SYSTEM OIL CAPACITY(GALLONS)						
37	TAIL ROTOR CANT ANGLE(DEGREES)						
38							
39							
40	ROTOR TIP SPEED AT DESIGN LIMIT		R.P.M.	POWER	FT/SEC		
41	-MAIN						
42	-TAIL						
43							
44	DESIGN THRUST OR LIFT ON	WING		M ROTOR		T ROTOR	
45	ULTIMATE L.F. FOR THE ABOVE LOADS						
46							
47	MATERIAL BREAKDOWN IN PERCENT		STEEL	ALUM	TI	COMPOSITE	OTHER
48	OF STRUCT.WEIGHT(PAGE 2,LINE57)						
49							
50	DESIGN SPEEDS AT S.L.(KNOTS)		LEVEL		DIVE		
51							
52	DESIGN SPEED AT BEST CRUISE		SPEED		ALTITUDE		
53	MAX. SPEED AND ALTITUDE		SPEED				ALTITUDE
54							
55							
56	MODEL FIRST FLIGHT DATE						
57	AIRFRAME UNIT WEIGHT						

*TOTAL USABLE CAPACITY.

TABLE A-5. ESTIMATED DESIGN/PERFORMANCE PARAMETERS FOR FIXED AND ROTARY WING AIRCRAFT

AIRCRAFT	ESTIMATED DESIGN/PERFORMANCE PARAMETERS
Fixed Wing	
AV-8A, F-4J	Fuselage Wetted Area
AV-8A	Fuselage Volume
KC-130F, F-4J	Max. Speed -- Mach Number
F-4N	Date of 1st Flight - Prototype
All Aircraft	Wing Wetted Area
All Aircraft	Total Wetted Area
C-1A, E-1B, RF-4B	Min. Time: Sea Level to 20K Ft.
Rotary Wing	
CH-53A	Specific Fuel Consumption -- Normal
SH-2F	Max. Rate of Climb -- Normal

TABLE A-6. GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

Most of the design/performance parameters are standard terms discussed in MIL-C-5011A, MIL-STD-1374A, and SD-24K, Volumes 1 and 2. To insure that proper values are used in the prediction equations of the two models, the following explanations and definitions are provided. Reference Tables A-8 and A-9 for a complete list of design/performance parameters.

Fixed Wing Aircraft

- Type A or B:

  A binary indicator parameter used to permit categorical differences between aircraft to be accounted for. For a Type A aircraft, this parameter is set equal to "0" (zero), and for a Type B aircraft is set equal to "1" (one). Type B aircraft include fighter, attack, reconnaissance (derivatives of fighter/attack), and electronic warfare; Type A is all other aircraft.

- Kinetic Energy (multi. of 100,000):

  The (Maximum Landing Weight in Lbs) times the (Landing Sink Speed -- Limit in $\text{Ft/Sec})^2$, i.e., KE = (Wt. in Lbs.) times $(\text{Speed in Ft./Sec.})^2$. Then KE is divided by 100,000 prior to use in a prediction equation. This is a modified definition and should not be confused with the standard definition in a physics text. Example -- (25,000 Lbs) times $(22.0\ \text{Ft/Sec})^2$

  = (25,000 Lbs) times ($484.0\ \text{Ft}^2/\text{Sec}^2$)

  = $12{,}100{,}000.0\ \text{Lbs}\cdot\text{Ft}^2/\text{Sec}^2$

  Then ($12{,}100{,}000.0\ \text{Lbs}\cdot\text{Ft}^2/\text{Sec}^2$) divided by 100,000.

  = $121.0\ \text{Lbs}\cdot\text{Ft}^2/\text{Sec}^2$

- . Date of 1st Flight -- Prototype,

  . Date of 1st Flight -- Series:

  Coded values equal to the number of months since January 1, 1950; i.e., January 1950 has the value of "1", February 1950 has the value of "2", ..., December 1950 is "12", December 1951 is "24", etc.

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

- Crew Size -- Cockpit or Total:
  "Cockpit" crew size applies to Type B fixed wing aircraft; and "Total" crew size applies to Type A fixed wing aircraft.

- Number of Movable Flight Control Surfaces:
  Includes flaps, spoilers, ailerons, speedbrake, slats, rudders, etc.

- Number of External Store Stations:
  The number of external attachment points for munitions.

- Flight Control Surface Area:
  Sum of the areas of the flaps spoilers, ailerons, speedbrake, ailerons, slats, rudders, etc.

- Wing Wetted Area:
  Value obtained by solving for wing wetted area in the expression

$$\frac{\text{Fuselage Wetted Area}}{\text{Internal Fuel Cap.}} = \frac{\text{Wing Wetted Area}}{\text{Int. Wing Fuel Cap.}}$$

- Total Wetted Area:
  The sum of fuselage wetted area and wing wetted area.

- Max. Rate of Climb at Sea Level:
  The maximum rate of climb calculated at military/intermediate power settings for turbofan and turbojet engines; at normal power settings for turboprop and turboshaft engines.

- Min. Time: Sea Level to 30K Ft.:
  Minimum time calculated at military/intermediate for turbofans and turbojets, or normal power settings for turboprop and turboshaft engines.

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

- Total Generator Elec. Power:

  Total electrical power supplied by all aircraft generators operating at rated power levels.

- Empty Weight:

  A configuration for design purposes, as defined in detail model specifications. Does not include crew, fuel, oil, armament, cargo, bombs, and disposable or special equipment.

- Max. T.O. Weight -- Cat. or Normal:

  Maximum take-off weight is the greatest weight for take-off established by Technical Orders, design requirements, or other specific recommendations of the procuring agency.

- Bypass Ratio:

  The fan duct air flow divided by the core air flow.

- Max. Speed -- Mach No.:

  Highest Mach Number that can be obtained across all design missions.

- . Afterburner Indicator,
  . Recce. Indicator,
  . EW Indicator,
  . A/C Carrier or Land Based:

  Binary indicator parameters used to permit categorical differences between aircraft to be accounted for.

- Flight Design Weight:

  Weight at which specified flight structural design requirements are met or are required to be met.

- Max. Speed at Sea Level:

  Maximum speed obtainable at Sea Level across all design missions.

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

- (Max. Rate of Climb) x (Type A or B),
  - (Max. Speed -- Mach No.) x (Type A or B),
  - (Max. Speed at Sea Level) x (Type A or B),
  - (Min. Combat Mission Time) x (Type A or B),
  - (Avionics Wt. Installed) x (Type A or B),
  - (Max. Wing Loading) x (Type A or B):

  These parameters are called interaction terms and are formed by the product of an indicator parameter (i.e., Type A or B) as it applies to a given aircraft and a design/performance parameter. See Section 5.5 and 6.1.1 of Volume II for a more detailed explanation.

- Number of Engines:

  The number of primary engines for aircraft of conventional design, and the number of primary lift/cruise engines for aircraft designs having primary lift/cruise engines plus auxiliary lift engines. The auxiliary lift engines must be accounted for and predicted separately.

- Total Aircraft Thrust -- Military:

  The sum of the rated thrust for each primary engine (e.g., lift/cruise) at military or intermediate power setting.

- Max. No. of Ext. Arm. Stores:

  Maximum number of munitions that can be carried externally by the aircraft. For example, the A-7B has 6 weapons pylons and each pylon can carry a maximum of 3 munitions. Therefore, 18 is the maximum number of armament stores.

- Landing Sink Speed -- Limit:

  The ultimate sink speed for which the aircraft is designed.

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

o
- Total Aircraft Thrust -- Military,
- Maximum Thrust per Engine,
- Max. Thrust to Installed Engine Weight,
- Max. Thrust to Max. Take-Off Weight,
- Max. Thrust to Max. Landing Weight,
- Military Thrust to Design Weight:

  Horsepower figures for aircraft with turboprop, turboshaft, or reciprocating engines were converted to thrust using

  $$F_t = \frac{300\ HP}{MPH}$$

o
- Max. Payload
- Max. Service Ceiling,
- Max. Combat Radius,
- Max. Combat Mission Time,
- Max. Speed at Sea Level,
- Max. Wing Loading:

  The maximum values across all design missions excluding the ferry mission

o
- Min. Time: Sea Level to 30K Ft.,
- Min. Combat Mission Time,
- Min. Stall Speed -- Approach Power,
- Min. Landing Distance -- Ground Roll,
- Min. Time: Sea Level to 20K Ft:

  The minimum values across all design missions excluding the ferry mission

o Max. Ldg. Wt. -- Arrested or Design:

The maximum arrested landing weight if the aircraft is carrier-based; the maximum design landing weight if the aircraft is land-based

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

Rotary Wing Aircraft

- Empty Weight:

  A configuration for design purposes, as defined in detail model specifications. Does not include crew, fuel, oil, armament, cargo, bombs, and disposable or special equipment.

- Max. Take-Off or Landing Weight:

  The data available for data base development consistently showed the two parameters to be equal in value. If a situation develops where the values are different, the recommended approach is to use the larger value.

- Crew Size -- Total:

  The total number of crew members for which the aircraft was designed, i.e., cockpit crew plus all other personnel normally assigned to the aircraft.

- No. of Troops:

  The number of troops that can be accommodated/carried by an aircraft having a primary mission of marine assault.

- No. of External Launch Points:

  The number of external attachment points for munitions with the exception of flares.

- Max. No. External Armament Stores:

  The maximum number of droppable ordnance items carried externally which may be accommodated by the aircraft.

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

- No. of External Torpedo Store Stations:
  The number of external attachment points which can accommodate torpedos.

- No. of Internal Sonobuoy Stores:
  The total number of individual sonobuoys carried internally by an aircraft.

- Tail Pylon Fold:
  A parameter whose value is "1" if the notional aircraft has a tail pylon fold and "0" if the aircraft does not have a folding tail.

- . Date of 1st Flt. -- Series,
  . Date of 1st Flt. -- Prototype,
  . Date of 1st Flt. -- Service,
  Coded values equal to the number of months since January 1, 1950; i.e., January 1950 has the value of "1", February 1950 has the value of "2", ... December 1950 is "12", December 1951 is "24", etc.

- Total Aircraft SHP -- Mil. or Int. Power:
  The product of the number of propulsion engines and the Military or intermediate shaft horsepower per engine.

- Military or Int. SHP per Engine:
  The SHP rating of a single engine operated at military or intermediate power setting.

- No. of Mission Variants:
  The number of different missions the aircraft is equipped to perform. The missions include anti-submarine warfare (ASW), marine assault (MA), vertical onboard delivery (VOD), and search and rescue (SAR).

TABLE A-6 (Cont.). GENERAL NOTES
FIXED AND ROTARY WING AIRCRAFT

- Total Rotor Disc Area (Sweep) -- Main + Tail:
  The area swept by one revolution of a main rotor blade plus the area swept by one revolution of a tail rotor blade.

- Main Rotor Disc Area (Sweep):
  The area swept by one revolution of a main rotor blade.

- Main Rotor Blade Area (Total):
  The sum of the area projected by each main rotor blade.

- Auxiliary Power Unit:
  A binary indicator parameter used to permit differences between aircraft having or not having an auxiliary power unit to be accounted for.

- Total Generator Electrical Power:
  Total electrical power supplied by all aircraft generators operating at rated power levels.

- . Max. Disc Loading,
  . Max. Rate of Climb -- Normal,
  . Max. Service Ceiling,
  . Max. Speed at Sea Level,
  . Max. Combat Radius,
  . Max. Combat Range:
  The maximum values across all design missions excluding the ferry mission.

- MA Indicator:
  A binary indicator parameter used to permit differences between aircraft having or not having marine assault as the primary mission to be accounted for. If the notional aircraft's primary mission is marine assault the parameter has the value of "1", otherwise it has a value of "0".

TABLE A-7. OMISSIONS AND SUBSTITUTIONS OF DESIGN/PERFORMANCE PARAMETERS

The following remarks reference all entries in the Design/Performance Data Bases for which omissions or substitutions were required.

<u>Fixed Wing Aircraft</u>

- o
  - . Turbine Inlet Temperature,
  - . Number of Turbine Stages,
  - . Number of Fan plus Compressor Stages:

    Data values were omitted for the E-1B and C-1A as these parameters are not applicable to reciprocating engines.
- o Specific Fuel Consumption:

  Data values were not available for the E-1B and C-1A.
- o Max. Take-Off Weight:

  For the KC-130F, KC-130R, P-3A, P-3B, and P-3C, the Max. Take-Off Weight (Normal) was used in place of Max. Take-Off Weight (Catapult).
- o Max. Landing Weight:

  For the KC-130F, KC-130R, P-3A, P-3B, and P-3C, the Max. Landing Weight (Design) was used in place of Max. Landing Weight (Arrested).
- o
  - . Min. Time: Sea Level to 20K Ft.,
  - . Min. Time: Sea Level to 30K Ft.:

    For the KC-130R the times associated with the mission for which the rate of climb at sea level is maximum were used instead of the true minimum time; for all other aircraft the same mission provided both the minimum time and maximum rate of climb.
- o Bypass Ratio:

  Data Values were omitted for the C-1A, C-2A, E-1B, E-2B, E-2C, KC-130F, KC-130R, P-3A, P-3B, and P-3C as this does not apply to aircraft with turboprop and reciprocating engines.

TABLE A-7 (Cont.). OMISSIONS AND SUBTITUTIONS OF
DESIGN/PERFORMANCE PARAMETERS

- Max. Combat Radius:

  Since a ferry mission was associated with the maximum combat radius given for the A-6E, the next largest radius value was entered in the data file.
- Number of Engine Parts:

  13 of the 32 aircraft are missing data values; these values were unobtainable from the engine manufacturer.

Rotary Wing Aircraft

No omissions or substitutions.

TABLE A-8. DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR FIXED WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
1	Crew Size -- Cockpit or Total	Yes	1.	10.	
2	No. of Move. Flt. Cont. Surf.	Yes	7.	26.	
3	No. of Fixed Inlets	No	0.	4.	
4	No. of Variable Inlets	Yes	0.	2.	
5	No. of Vertical Tails	Yes	1.	4.	
6	Wing Sweep at 1/4 Chord (Deg)	Yes	-1.32	68.0	
7	Max. No. of Ext. Armament Stores	Yes	0.	30.	
8	Landing Sink Speed -- Limit (Ft/Sec)	Yes	9.0	26.0	Needed to calculate Kinetic Energy
9	Tail Span (Ft)	No	11.3	52.7	
10	Wing Span -- Unfolded (Ft)	No	25.27	132.6	
11	Wing Span -- Folded (Ft)	Yes	22.5	49.42	Data Range - Carrier based only
12	No. of Wing Plus Tail Folds	Yes	0.	3.	
13	Max. Aircraft Length (Ft)	Yes	41.3	116.83	
14	Max. Aircraft Height (Ft)	Yes	11.5	38.4	
15	Mean Aerodynamic Chord -- MAC (Ft)	No	7.25	16.75	
16	Wheelbase (Ft)	Yes	11.42	34.83	
17	Main Gear Tread (Ft)	No	7.8	31.17	
18	Fuse. Wetted Area (Sq. Ft.)	Yes	372.	3460.	
19	Wing Wetted Area (Sq. Ft.)	Yes	435.04	2285.94	
20	Wing Area (Sq. Ft.)	Yes	201.1	1745.5	
21	Total Wetted Area (Sq. Ft.)	No	807.04	5745.94	
22	Fuselage Volume (Cubic Ft.)	Yes	565.	9060.	
23	Aspect Ratio	Yes	2.91	10.09	
24	No. of Ext. Store Stations	Yes	0.	10.	
25	Flt. Control Surf. Area (Sq. Ft.)	Yes	106.56	1297.0	
26	Gun Weight (Lbs.)	No	0.	646.0	
27	No. of Guns	Yes	0.	2.	
28	Pres. Fuselage Volume (Cubic Ft.)	Yes	0.	8070.	

TABLE A-8 (Cont.). DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR FIXED WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
29	Avionics Wt. Installed (Lbs.)	Yes	520.0	11631.1	
30	Avionics Wt. Uninstalled (Lbs.)	No	130.19	9805.4	
31	(Min. Time: S.L. to 30K Ft)^2	No	9.61	1406.25	
32	Aux. Power Unit (1=yes; 0=no)	No	0.	1.	
33	Total Generator Elec. Power (KVA)	Yes	9.	180.	
34	Total ECS Weight (Lbs)	Yes	100.56	1718.1	
35	Kinetic Energy (per 100,000) = (Max.Ldg.Wt.)x(Ldg.Sink Speed -- Limit)^2 (Lbs Ft^2/Sec^2)	Yes	24.336	316.21	
36	Fuel Cap. Int. Wing (Lbs.)	No	2836.	47328.	
37	Fuel Cap. Int. Fuse (Lbs.)	No	0.	25758.	
38	Fuel Cap. Ext. Tanks (Lbs.)	No	0.	18496.	
39	Fuel Cap. Max. Int. (Lbs.)	Yes	5154.	71808.	
40	Total Fuel Capacity (Lbs.)	Yes	6786.	90304.	
41	No. of Ext. Tanks	Yes	0.	5.	
42	No. of Int. Tanks	Yes	2.	12.	
43	No. of Engines	Yes	1.	4.	
44	Max. Thrust per Engine (Lbs.)	Yes	8500.	21500.	Turbojet and turbofan only
45	Total Aircraft Thrust -- Mil. (Lbs.)	Yes	8500.	24700.	Turbojet and turbofan only
46	Afterburner Indicator (1=yes; 0=no)	Yes	0.	1.	Indicator Variable - Caution
47	Max. Engine Diameter (Inches)	Yes	30.2	51.42	Turbojet and turbofan and turboprop
48	Max. Engine Length (Inches)	Yes	104.	267.66	Turbojet and turbofan and turboprop
49	Engine Wt. Inst. per Engine (Lbs.)	Yes	1471.9	4791.0	Turbojet and turbofan and turboprop
50	No. of Fan Plus Compressor Stages	No	11.	17.	Turbojet and turbofan and turboprop
51	No. of Turbine Stages	No	2.	6.	Turbojet and turbofan and turboprop
52	Max. Compression Ratio	Yes	11.0	22.0	Turbojet and turbofan only
53	Spec. Fuel Consumption	Yes	0.363	0.89	
54	Turbine Inlet Temp. (Deg. F)	Yes	1580.	2300.	Turbojet and turbofan and turboprop
55	Empty Weight (Lbs.)	Yes	9624.	74095.	
56	Flight Design Weight (Lbs.)	Yes	12504.	155000.	
57	Design Load Factor -- Subsonic	Yes	2.5	8.5	

TABLE A-8 (Cont.). DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR FIXED WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
58	Max. T.O. Wt. -- Cat. or Norm (Lbs.)	Yes	24500.	79588.	Data Range - Carrier based only
59	Max. Ldg. Wt. -- Arr. or Design (Lbs.)	Yes	14500.	51830.	Data Range - Carrier based only
60	Max. Payload (Lbs.)	Yes	0.0	55546.	
61	Bypass Ratio	No	0.0	6.23	
62	Max. Wing Loading (Lbs./Sq. Ft.)	Yes	51.0	121.5	
63	Max. Rate of Climb at S.L. (Ft.per Min.)	Yes	1120.	12700.	
64	Min. Time (Min.): S.L. to 30K Ft.	No	3.1	10.9	Data Range - Carrier based only
65	Max. Serv. Ceil. -- 100 FPM (Ft.)	Yes	15800.	44600.	
66	Max. Thrust (Lbs) to Eng. Wt. Instl.(Lbs)	Yes	2.621	6.976	Turbojet and turbofan only
67	Max. Thrust (Lbs) to Max. T.O. Wt.(Lbs)	Yes	0.286	.874	Turbojet and turbofan only
68	Max. Thrust (Lbs) to Max. Ldg. Wt.(Lbs)	No	0.420	1.272	Turbojet and turbofan only
69	Max. Combat Radius (N.Mi.)	Yes	150.	1977.	
70	Min. Combat Mission Time (Hrs)	Yes	0.50	11.1	
71	Max. Combat Mission Time (Hrs)	Yes	1.95	13.48	
72	Max. Speed -- Mach No.	Yes	0.32	2.25	
73	Min. Stall Speed -- Approach Power (Kn)	No	0.0	118.	
74	Min. Ldg. Distance (Ft)	No	0.0	5315.	
75	Max. Speed at S.L. (Kn)	No	201.	806.	
76	Recce. Indicator (1=yes; 0=no)	No	0.	1.	Indicator Variable - Caution
77	EW Indicator (1=yes; 0=no)	Yes	0.	1.	Indicator Variable - Caution
78	Date of 1st Flt. -- Proto. (Months since 1 Jan. 1950)	No	61.	309.	
79	Date of 1st Flt. -- Series (Months since 1 Jan. 1950)	No	36.	265.	
80	$(\text{Total Fuel Capacity})^2$ (Mult. of 100 Lbs)	No	125033.	11960530.	
81	$(\text{Fuel Cap. Ext. Tanks})^2$ (Mult. of 100 Lbs)	No	0.0	1183744.	
82	No. of Engine Parts	No	2688.	15000.	Counted differently by manufacturers

TABLE A-8 (Cont.). DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR FIXED WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Range Min.	Max.	Comments
83	A/C Carrier or Land Based (1=Carrier; 0=Land)	No	0.	1.	Indicator Variable - Caution
84	Min. Time (Min): S.L. to 20K Ft.	No	1.8	5.8	Turbojet and turbofan
85	(Min. Time (Min): S.L. to 20K Ft.)^2	No	3.24	33.64	Turbojet and turbofan
86	Flt. Design Wt.(Lbs)to Max. T.O. Wt.(Lbs)	Yes	0.510	0.863	Turbojet and turbofan
87	Mil. Thrust (Lbs) to Design Wt.(Lbs)	Yes	0.365	0.895	Turbojet and turbofan
88	Max. Thrust (Lbs) or SHP (SHP) to Eng. Wt. Uninst. (Lbs)	No	2.10	6.36	Turbojet and turbofan
89	Specific Thrust or Specific SHP	No	27.42	105.05	Turbojet and turbofan
90	Max. Airflow (Lbs/Sec)	No	137.	445.	Turbojet and turbofan
91	Max. Pressure Ratio	No	10.95	21.89	Turbojet and turbofan
92	Fuel to Air Ratio	No	0.013	0.024	Turbojet and turbofan
93	Eng. Wt. Uninst. per Eng. (Lbs)	No	1458.	4860.	Turbojet and turbofan
94	Max. Thrust or SHP per Eng. (Lbs or SHP)	No	8500.	21500.	Turbojet and turbofan
95	Type A or B (1=B; 0=A)	Yes	0.	1.	Indicator Variable - Caution
96	(Max. Rate of Climb) X (Type A or B)	No	0.	13500.	Indicator variable used - caution
97	(Max. Speed -- Mach No.) X (Type A or B)	Yes	0.	2.25	Indicator variable used - caution
98	(Max. Speed at S.L.) X (Type A or B)	No	0.	805.	Indicator variable used - caution
99	(Min. Combat Mission Time) X (Type A or B)	Yes	0.	2.90	Indicator variable used - caution
100	(Avionics Wt. Inst.) X (Type A or B)	Yes	0.	4657.	Indicator Variable used - caution
101	(Max. Wing Loading) X (Type A or B)	Yes	0.	121.5	Indicator variable used - caution

TABLE A-9. DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR ROTARY WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
1	Empty Weight (Lbs)	Yes	8652.	23083.	
2	Max. Take-Off or Landing Weight (Lbs)	Yes	12800.	36378.	
3	Design Load Factor	No	2.25	3.0	
4	Crew Size -- Total	Yes	3.	5.	
5	No. of Troops	Yes	17.	38.	
6	No. of Main Rotor Blades	Yes	3.	6.	
7	No. of Tail Rotor Blades	Yes	3.	5.	
8	No. of Engines	No	2.	2.	
9	Main Rotor Radius (Ft)	Yes	22.0	36.12	
10	Tail Rotor Radius (Ft)	No	4.1	8.0	25.5 for tandem rotor
11	Fuselage Length -- Folded (Ft)	Yes	40.25	67.2	
12	Fuselage Depth -- Folded (Ft)	Yes	6.75	9.2	
13	Fuselage Width -- Folded (Ft)	No	5.42	8.8	
14	Aircraft Length -- Operating (Ft)	Yes	52.6	88.3	
15	Aircraft Span -- Operating (Ft)	Yes	44.0	72.0	
16	Aircraft Height -- Operating (Ft)	Yes	15.1	24.9	
17	Wheelbase (Ft)	Yes	16.7	27.25	
18	Main Gear Tread (Ft)	Yes	10.0	13.0	
19	Main Rotor Blade Chord	No	18.06	26.0	
20	Tail Rotor Blade Chord	No	7.34	15.4	18.75 for tandem rotor
21	No. External Launch Points	Yes	0.	4.	
22	Max. No. External Armament Stores	No	0.	4.	
23	No. External Torpedo Store Stations	No	0.	4.	
24	No. Internal Sonobuoy Stores	No	0.	15.	
25	Tail Pylon Fold (1=yes; 0=no)	Yes	0.	1.	Indicator Variable - Caution
26	Date of 1st Flt. -- Series (Months since 1 January 1950)	No	111.	178.	
27	Date of 1st Flt. -- Prototype (Months since 1 January 1950)	No	112.	268.	
28	Date of 1st Flt. -- Service (Months since 1 January 1950)	No	135.	281.	
29	Total Aircraft SHP -- Mil. or Int. Power (SHP)	Yes	2700.	7390.	

TABLE A-9 (Cont.). DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR ROTARY WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
30	Total Aircraft SHP -- Normal Power (SHP)	No	2300.	6460.	
31	Military or Int. SHP per Engine (SHP)	Yes	1350.	3695.	
32	Normal SHP per Engine (SHP)	No	1150.	3230.	
33	Total Aircraft SHP -- Normal Power to Max. Take-Off Weight (Lbs)	No	0.1179	0.1289	
34	Max. Engine Diameter (Inches)	No	20.7	24.0	
35	Max. Engine Length (Inches)	No	59.0	79.0	
36	Engine Weight Installed per Engine (Lbs)	Yes	290.0	707.0	
37	No. of Fan Plus Compressor Stages	No	10.	14.	
38	No. of Turbine Stages	No	3.	4.	
39	Max. Compression Ratio	No	8.3	14.1	
40	Specific Fuel Consumption -- Mil. or Int.	No	0.476	0.60	
41	Specific Fuel Consumption -- Normal	No	.472	0.62	
42	Turbine Inlet Temp. (Deg. F)	Yes	1740.	2000.	
43	Mil. SHP per Eng. (SHP) to Eng. Wt. Inst. per Eng. (Lbs)	Yes	3.36	5.23	
44	Total Aircraft SHP -- Mil. or Int. Power to Max. Take-Off Wt. (Lbs)	Yes	0.13	0.21	
45	No. of Mission Variants	No	1.	3.	
46	No. of Engine Parts	No	6175.	10293.	
47	Main Rotor Gear Ratio	Yes	0.0135	0.107	
48	Main Rotor Tip Speed at Design Limit	No	686.5	875.0	
49	Main Rotor Transmission Limit -- SHP	Yes	1250.	7850.	
50	Main Rotor Transmission Limit -- RPM	Yes	13600.	19500.00	
51	Power Transmission Weight (w/o Rotor)(Lbs)	Yes	1744.0	4064.1	
52	Rotor Weight (Lbs)	Yes	1321.1	4504.7	
53	Blade Loading (PSF)	Yes	0.0714	0.0864	
54	Engine RPM -- Mil. or Int. Power (RPM)	No	13600.	19500.	
55	Total Rotor Disc Area (Sweep) -- Main + Tail (Sq Ft)	No	1573.3	4299.2	
56	Total Blade Area -- Main + Tail (Sq Ft)	No	170.1	391.0	

TABLE A-9 (Cont.). DESIGN/PERFORMANCE PARAMETERS, USAGE AND RANGE OF VALUES FOR ROTARY WING AIRCRAFT

Var. No.	Variable Name	Variable used in an Equation	Range of Historical Data Min.	Range of Historical Data Max.	Comments
57	Main Rotor Disc Area (Sweep) (Sq Ft)	Yes	1520.5	4098.1	
58	Tail Rotor Disc Area (Sweep) (Sq Ft)	No	52.8	201.1	2042.8 for tandem rotor
59	Main Rotor Blade Area per Blade (Sq Ft)	No	37.5	62.5	
60	Tail Rotor Blade Area per Blade (Sq Ft)	No	2.05	4.0	39.84 for tandem rotor
61	Main Rotor Blade Area (Total) (Sq Ft)	Yes	112.5	375.0	
62	Tail Rotor Blade Area (Total) (Sq Ft)	No	8.2	16.0	119.5 for tandem rotor
63	Avionics Weight Installed (Lbs)	Yes	368.0	2577.3	
64	Avionics Weight Uninstalled (Lbs)	No	307.3	1917.8	
65	Total ECS Weight (Lbs)	Yes	69.83	314.2	
66	Air Conditioning Weight (Lbs)	No	38.47	236.8	
67	Anti-icing Weight (Lbs)	No	22.8	186.1	
68	Auxiliary Power Unit (1=yes; 0=no)	No	0.	1.	Indicator Variable - Caution
69	No. of Aircraft Generators	No	2.	2.	
70	Generator Electrical Power per Gen.(KVA)	No	20.	40.	
71	Total Generator Electrical Power (KVA)	Yes	40.	80.	
72	Fuel Capacity Internal (Lbs)	Yes	1876.8	5929.6	
73	Fuel Capacity Auxiliary (Lbs)	No	0.0	10200.0	
74	Total Fuel Capacity (Lbs)	Yes	2584.0	14538.4	
75	No. of Internal Tanks	Yes	2.	4.	
76	No. of Auxiliary Tanks	Yes	0.	5.	
77	Max. Disc Loading (PSF)	Yes	5.63	12.2	
78	Vertical Rate of Climb at Sea Level -- Mil. (Ft per Min)	Yes	0.0	2500.	
79	Absolute Hovering Ceiling -- Mil. (Ft)	No	0.0	14700.	
80	Max. Rate of Climb -- Normal (Ft per Min)	Yes	1130.	2180.	
81	Max. Service Ceiling (Ft)	Yes	12100.	17500.	
82	Max. Speed at Sea Level (Kn)	Yes	126.	166.	
83	Max. Combat Radius (N.Mi.)	Yes	100.	250.	
84	Max. Combat Range (N.Mi.)	Yes	204.	500.	
85	Max. Speed at Alt. (Kn)	Yes	126.	166.	
86	Assoc. Alt. for Max. Speed (Ft)	No	0.0	7000.	
87	Avg. Cruising Speed -- Primary Mis. (Kn)	No	116.0	150.	
88	Cruising Altitude -- Primary Mis. (Ft)	No	0.0	10000.	
89	MA Indicator (1=yes; 0=no)	Yes	0.	1.	Indicator Variable - Caution

LIST OF ACRONYMS AND SYMBOLS

A	Attack
AAW	Air-To-Air Warfare
AEW	Aircraft Early Warning
Arr.	Arrested Landing
ASUW	Anti-Surface Warfare
ASW	Antisubmarine Warfare
A/C	Aircraft
Cat.	Catapult
COD	Carrier Onboard Delivery
CTOL	Conventional Takeoff or Landing
ECS	Environmental Control System
EW	Electronic Warfare
F	Fighter
FPM	Feet Per Minute
HELO	Helicopter
Inst	Installed
Int.	Intermediate
k	Ridge Parameter
KVA	Kilovolt-Ampere
ln(MFHBF)	Natural Log of MFHBF
MA	Marine Assault
MFHBF	Mean Flight Hours Between Failures
Mil.	Military
NATOPS	Naval Air Training and Operating Procedures Standardization
PSF	Pounds Per Square Foot
r	Correlation Coefficient
R^2	Coefficient of Determination
Recce	Reconnaissance
SAC	Standard Aircraft Characteristics
SAR	Search and Rescue
SBAMS	Sea Based Air Master Study
S.L.	Sea Level
SSE	Sum of Squares of Error
SSR	Sum of Squares Due to Regression
STOL	Short Takeoff or Landing
STOVL	Short Takeoff and Vertical Landing
TKR	Tanker
TYPE A	Carrier Based Aircraft -- ASW/ASUW, AEW, COD, Tanker, Etc.
TYPE B	Carrier Based Aircraft -- Fighter, Attack, Reconnaissance, Electronic Warfare
TYPE L	Land-Based Aircraft -- Patrol ASW, Tanker
Uninst	Uninstalled
VIF	Variance Inflation Factor
VOD	Vertical Onboard Delivery
V/STOL	Vertical/Short Takeoff or Landing
WUC	Work Unit Code
3M	Maintenance and Material Management System