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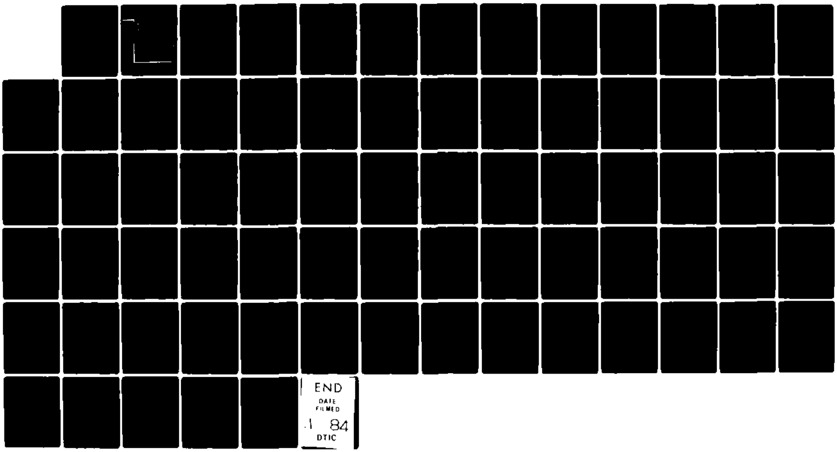

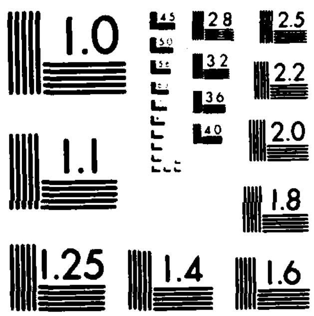
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AIR FORCE

HUMAN RESOURCES

AD-A136557

MAINTENANCE METRICS TO FORECAST RESOURCE DEMANDS OF WEAPON SYSTEMS

By

Donald K. Hindes
Gary A. Walker
David H. Wilson

Boeing Aerospace Company
P.O. Box 3999
Seattle, Washington 98124

Frank Maher

LOGISTICS AND HUMAN FACTORS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

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Final Report

LABORATORY

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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Technical Director
Logistics and Human Factors Division

ALFRED A. BOYD, JR., Colonel, USAF
Commander

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the methodology and results of a 15-month effort to develop maintenance metrics to forecast resource demands of weapon systems. Increased concern with the rising cost to support weapon systems currently in operation, as well as those in development, has created the need for more accurate methods of projecting maintenance requirements. The objective of the research was to alleviate this need by identifying, determining, and integrating those measurable weapon systems parameters that are necessary and sufficient to predict and quantify the drivers of maintenance resource demands.

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The study was accomplished as three separate but similar efforts. The data base was divided into separate data bases for cargo/transport, bomber, and fighter aircraft. Separate sets of metrics were then developed for each of the three classes of aircraft from these separate data bases.

This final report is intended to be a summary overview of the study project. Study descriptions and findings include (a) study aircraft/base case selection, (b) critical equipment selection, (c) *maintenance impact parameter* selection, (d) data base acquisition and integration, (e) maintenance impact analysis, (f) maintenance metric model development, and (g) maintenance demand causal analysis.

The most important end products of this study are new maintenance metrics that can increase the accuracy with which the maintenance demand rates of the various aircraft subsystems are predicted.

SUMMARY

Objective

The objective was to isolate significant relations between maintenance resource demands and selected candidate maintenace impact parameters for three classes of Air Force aircraft (bombers, transports, and fighters). The relations were to be (a) based on useful historical field experience data, (b) determined through multiple correlation analyses and verifications and (c) structured in a form that could be used to estimate maintenance demand in new aircraft or new basing situations for use in projecting manpower or other resource requirements.

Background/Rationale

Increased concern with the rising cost to support weapon systems that currently are in operation, as well as those in development, has created the need for more accurate meth ls of projecting maintenance requirements. This research and development (R&D) effort identifies metric relations for weapon system analyses that can predict and quantify the drivers of maintenac r source demands.

Approach

The approach was to collect, review, and catalog a large data base containing a great variety of design, operations, and environmental factors that might conceivably influence maintenance demands. This data base was then analyzed to identify those factors that appeared to be strongly correlated with the expenditure of maintenance resources. These maintenance impacts were structured parametrically and cataloged for future use. The detected maintenance impacts were then verified and combined into mathematical maintenance metric regression models for each item of equipment studied. The resulting models predict maintenance action demand based on selected design, operational, and environmental factors that impact the maintenance of each equipment item.

Specifics

This study was accomplished in three phases over 48 months. Each phase was accomplished as an eight-task effort comprising (a) literature search, (b) aircraft/base and study equipment selection, (c) maintenance impact parameter identification, (d) data base acquisition and integration, (e) maintenance impact parameter analysis and prioritization, (f) maintenance metrics model development, (g) maintenance weightings development, and (h) model verification and causal linkage analysis.

Phase I explored the feasibility of developing general maintenance impact estimating statistical models for the avionic and engine subsystems of the Air Force aircraft. Phase II extended the feasibility study to the rest of the common aircraft/base cases. Phase III expanded the statistical sample to 62 aircraft/base cases and developed separate mathematical model sets for bomber, fighter, and cargo/transport aircraft.

An example of a statistical relation is that wheel and tire maintenance demands were found to be related only indirectly with sortie rate, but directly with such maintenance impact factors as average landing weights, landing speeds, and number of landings. Such relations were used with actual data in a Logistics Composite Model (LCOM) simulation of C-135 operations at a specific base as a verification. These and other results were further verified by experts in the field.

Conclusions/Recommendations

The useful products consisted of (a) an extensive data base on the common subsystems of Air Force aircraft, (b) an extensive catalog of parametric maintenance impact estimating relationships, (c) maintenance metric mathematical models, and (d) causal explanations (i.e., verified by experts in the field) of the factors underlying the maintenance demands of aircraft equipment.

Most of these improved metrics can be used now by the Air Force in prediction and estimation efforts for (a) manpower determination studies, (b) cost-of-ownership studies, (c) new basing and deployment planning, and (d) design trade studies for future aircraft. A few require further investigation of causal relations. The major future effort is to derive similar relations for combat environments to supplement the peacetime data bases and relations developed in the study.

PREFACE

This technical report documents work performed under Contract No. F33615-77-C-0075, Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems.

The study provided statistically valid samples of cargo/transport, bomber, and fighter aircraft equipment maintenance demands, design characteristics, operational factors, and environmental factors. These data were used to develop more accurate maintenance metrics for each class of aircraft (cargo/transport, bomber, fighter) for transition to the user community. The details of the statistical da .., maintenance impacts, maintenance demand causality, and the resulting maintenance metrics mathematical models are contained in three supplemental volumes to this TR; (1) Cargo/Transport Users' Guide, (2) Bomber Users' Guide, (3) Fighter Users' Guide.

This study contract was performed by the Boeing Aerospace Company Product Support/Experience Analysis Center (PS/EAC), Seattle, Washington. USAF Contract F3615-77-C-0075 was initiated under Exploratory Development Area PMS 77-43 (1124). Work was accomplished under the direction of the Logistics and Human Factors Division of the Air Force Human Resources Laboratory with Mr. Frank Maher as the Work Unit Scientist and Air Force Contract Monitor.

Experience Analysis Center program technical leader was George R. Herrold. Principal program analysts were Donald K. Hindes, Gary A. Walker, and David H. Wilson.

The Boeing Aerospace Company wishes to express their appreciation for the technical assistance and data provided by (a) Air Force Logistics Command Headquarters, Aeronautical Systems Division, and Air Force Maintenance and Supply Management Engineering Team, Wright-Patterson AFB, Ohio, (b) Military Airlift Command (MAC) Headquarters, and Air Weather Service (MAC) Environmental Technical Applications Center, Scott AFB, Illinois, (c) Air Force Europe Headquarters, Ramstein AB, Germany, (d) Strategic Air Command Headquarters, Offutt AFB, Nebraska, (e) Tactical Air Command Headquarters, Langley AFB, Virginia, (f) 36th TFW, Bitburg AB, Germany, (g) 58th TTW, Luke AFB, Arizona, (h) 60th MAW, Travis AFB, California, (i) 92nd BW, Fairchild AFB, Washington, (j) 354th TFW,

Myrtle Beach AFB, South Carolina, (k) 355th TFW, Davis-Monthan AFB, Arizona, (l) 380th BMW, Plattsburgh AFB, New York, (m) 63rd MAW, Norton AFB, California, (n) 22nd BW, March AFB, California, (o) 35th TFW, George AFB, California, (p) 320th BW, Mather AFB, California, (q) 23rd TFW, England AFB, Louisiana, (r) 31st TFW, Homestead AFB, Florida, (s) 33rd TFW, Eglin AFB, Florida, (t) 27th TFW, Cannon AFB, New Mexico, (u) 49th TFW, Holloman AFB, New Mexico, (v) 347th TFW, Moody AFB, Georgia, (w) 19th BW, Robins AFB, Georgia, (x) 437th MAW, Charleston AFB, South Carolina, (y) 317th TAW, Pope AFB, North Carolina, (z) 68th BW, 4th TFW, Seymour Johnson AFB, North Carolina, (aa) 366th TFW, Mountain Home AFB, Idaho, (bb) 388th TFW, Hill AFB, Utah, (cc) 438th MAW, McGuire AFB, New Jersey, (dd) 436th MAW, Dover AFB, Delaware, (ee) 1st TFW, Langley AFB, Virginia, (ff) 435th TAW, Rhein-Main AB, Germany, (gg) 50th TFW, Hahn AB, Germany, (hh) 86th TFG, Ramstein AB, Germany, (ii) 52nd TFW, Spangdahlem AB, Germany, (jj) 32nd TFS, Camp New Amsterdam, Netherlands, (kk) 20th TFW, RAF Upper Heyford, England, (ll) 10th TRW, RAF Alconbury, England, (mm) 81st TFW, RAF Bentwaters, England, (nn) 513th TAW, RAF Mildenhall, England, (oo) 48th TFW, RAF Lakenheath, England, (pp) 96th BW, Dyess AFB, Texas, (qq) 7th BW, Carswell AFB, Texas, (rr) 314th TAW, Little Rock AFB, Arkansas, (ss) 416th BW, Giffiss AFB, New York, (tt) 509th BW, Pease AFB, New Hampshire, (uu) 42nd BW, Loring AFB, Maine, (vv) 28th BW, Ellsworth AFB, South Dakota, (ww) 5th BW, Minot AFB, North Dakota, (xx) 319th BW, Grand Forks AFB, North Dakota, (yy) 62nd MAW, McChord AFB, Washington.

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1.0 INTRODUCTION AND BACKGROUND

This technical report describes work accomplished and findings for the and Logistics and Human Factors Division study effort, "Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems."

Phases I and II of the maintenance metrics study were intended to explore the feasibility of developing maintenance impact estimating statistical models for the various subsystems of Air Force aircraft. The statistical data base utilized for this effort was composed of historical field data on selected maintenance, equipment design, operational, and environmental characteristic parameters.

The research subjects on which these data were obtained consisted of selected common aircraft equipment within a nine-case sample of U. S. Air Force aircraft/base combinations. This sample spanned the types of aircraft used by the Air Force (bomber, fighter, transport, and trainer) and the various ground base environments experienced.

This data base was then analyzed for possible causal factors for the expenditure of maintenance resources. These maintenance impacts were structured parametrically and cataloged for future use. The detected maintenance impacts were then combined into mathematical maintenance metric models for each item of equipment studied. These models predict maintenance action demand based on significant design, operational, and environmental factors which impact the maintenance of each equipment item. Validation of the models was performed through testing within the context of LCOM simulations.

The Phase I/II study and findings[1] demonstrated the feasibility of developing credible maintenance demand estimators to augment present methodology.

The Phase III study built on the findings of Phases I and II. It was based directly on the approach taken and the experience gained during those initial study efforts.

1.1 RATIONALE AND OBJECTIVE

The rising cost to support weapon systems currently in operation, as well as those in development has created the need for more accurate methods of projecting maintenance requirements. There are two cost driver variables that are generally understood by all. These are the manpower and material or resources to maintain the weapon system. In a study conducted on the life cycle cost of the C-130E

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1. Donald K. Hindes, et. al., Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems. Five Volume Boeing Aerospace Company document:

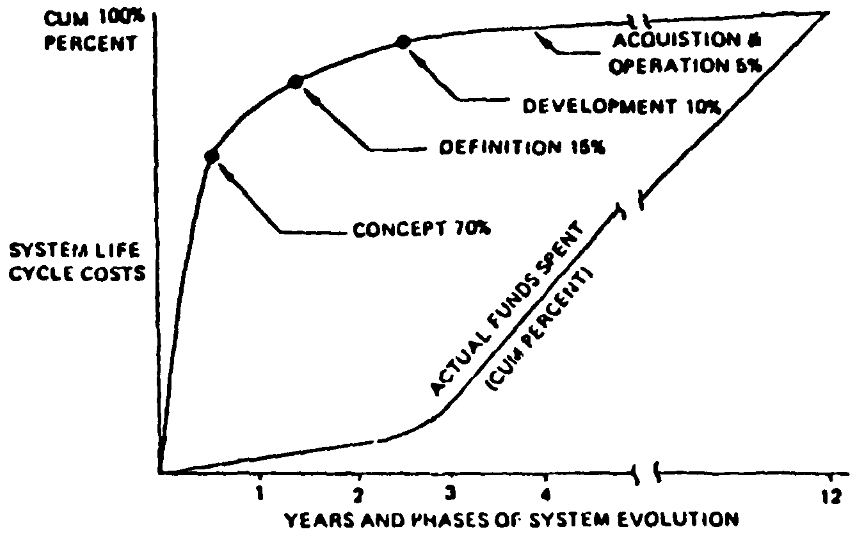
   D194-10089-1, Revision A, Analysis and Evaluation, February 1980
   D194-10089-2, Revision A, Parameter Prioritization, October 1980
   D194-10089-3, Revision A, Maintenance Metrics and Weightings, October 1980
   D194-10089-4, Revision A, Analysis and Results of Metrics and Weightings, November 1980
   D194-10089-5, Final Report, October 1980

aircraft it was determined that labor accounted for 70% of the 15 year cumulative operational and ;support cost, resources (material) approximately 18%, with the remaining being attributed to fuel and base support. The C-130E experience is typical of the other systems in Air Force inventory.

The major proportion of total operating and support cost incurred for labor and material has developed considerable concern for the manpower and resources required to support weapon systems currently in operation, as well as those in development. A study of maintenance and reliability impact on system support costs showed that some 70% of the life cycle cost funds of a new weapon system are essentially committed in the concept phase by initial planning decisions (Figure 1).

This semi-predetermined expenditure has created the need for more accurate methods of projecting maintenance and manpower requirements early in the design process so that trades can be made to reduce long term resource demands. Meeting this need requires the development of realistic predictive measures of maintenance rates for all of the diverse equipment that makes up a weapon system.

In addition, the impact of operations and environmental conditions need to be identified to ensure the accuracy of the newly developed maintenance metrics under the diverse conditions met by fielded weapon systems.



SYSTEMS FUNDS COMMITTED BY INITIAL PLANNING DECISIONS *

FIGURE 1

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*Planning Decisions made in later phases can still significantly impact cost.

To date, the manpower and other resource requirements essential to the operations and support (O&S) of a weapon system have been determined using the traditional "flying hours" and "sortie rate" measures. The deficiencies of these traditional measures are well known and such measures frequently are found to be totally irrelevant (e.g., maintenance on a gun subsystem is generated by factors like the number of rounds fired, and is not affected by the number of flying hours or sorties). These traditional measures are also insensitive to variations in operations and environmental conditions (for example, many avionics equipments may operate or are cycled on the ground greatly in excess of related flying hours or number of sorties). The present difficulties then lie in the fact that the currently used metrics do not consider the inherent differences between the individual subsystems of a weapon system and are relatively insensitive to operational and environmental conditions.

Therefore, the objective of this subject research was to alleviate the above deficiencies by identifying, determining, and integrating those measurable weapon system parameters which are necessary and sufficient to form more accurate metrics and weightings with which to predict system maintenance demands.

The objectives of Phases I and II of the overall study were to develop the research data base acquisition and integration methodologies; to develop the analysis and metrics development methodologies; and to demonstrate the feasibility of obtaining the overall research objective through the experimental derivation and validation of general maintenance action demand predictor models for Air Force aircraft subsystems.

The objective of Phase III for this study was to refine and expand the results of Phases I and II to increase the usability and credibility of the maintenance metrics and weightings developed from them. Phase III refines the maintenance action demand predictor models from the the general models for all Air Force aircraft developed during Phases I and II to three sets of class-specific models, one each for bombers, transports, and fighters. At the same time, the statistical validity of the resulting models is improved by expanding the data case sample size of each aircraft class beyond the threshold of "sparse" statistical samples. This greatly increases confidence that the developed models are in accordance with the rules and conventions of statistical analysis. In addition, model credibility is enhanced by investigation and explanation of any counterintuitive logic and/or anomalies that appear within the developed models.

1.2 OVERVIEW OF STUDY

The motivation behind the maintenance metrics development effort was the idea that much can be learned about predicting maintenance demand rates by looking at actual historical maintenance data on selected items of hardware and how and why these rates vary with changes in design, operational, and environmental parameters. This idea continued to serve as the central theme through all three phases of this study. Phase III was a logical extension of Phases I and II for improving the efficiency and user value of the exploratory work already accomplished. Phase III expanded the data base to cover additional aircraft models and aircraft/base data cases. The data base could then be used to develop maintenance demand predictor models that were derived from as much of the Air Force aircraft inventory and basing situations as study resources and time would allow.

Exploration of the basic underlying causal factors of maintenance demand was also a goal of the maintenance metrics development effort during Phase III.

The general task-oriented approach taken to accomplish the maintenance metrics development effort is illustrated in Figure 2 and summarized as follows:

1. Search and Review Literature, Develop Bibliography
   Review related studies and research dealing with maintenance rates and causes. Developed and documented a bibliography of relevant references.

2. Select Aircraft/Base Study Sample
   The 62 aircraft/bases that were selected for study includes the major aircraft in the Air Force inventory and most of their operating environments.

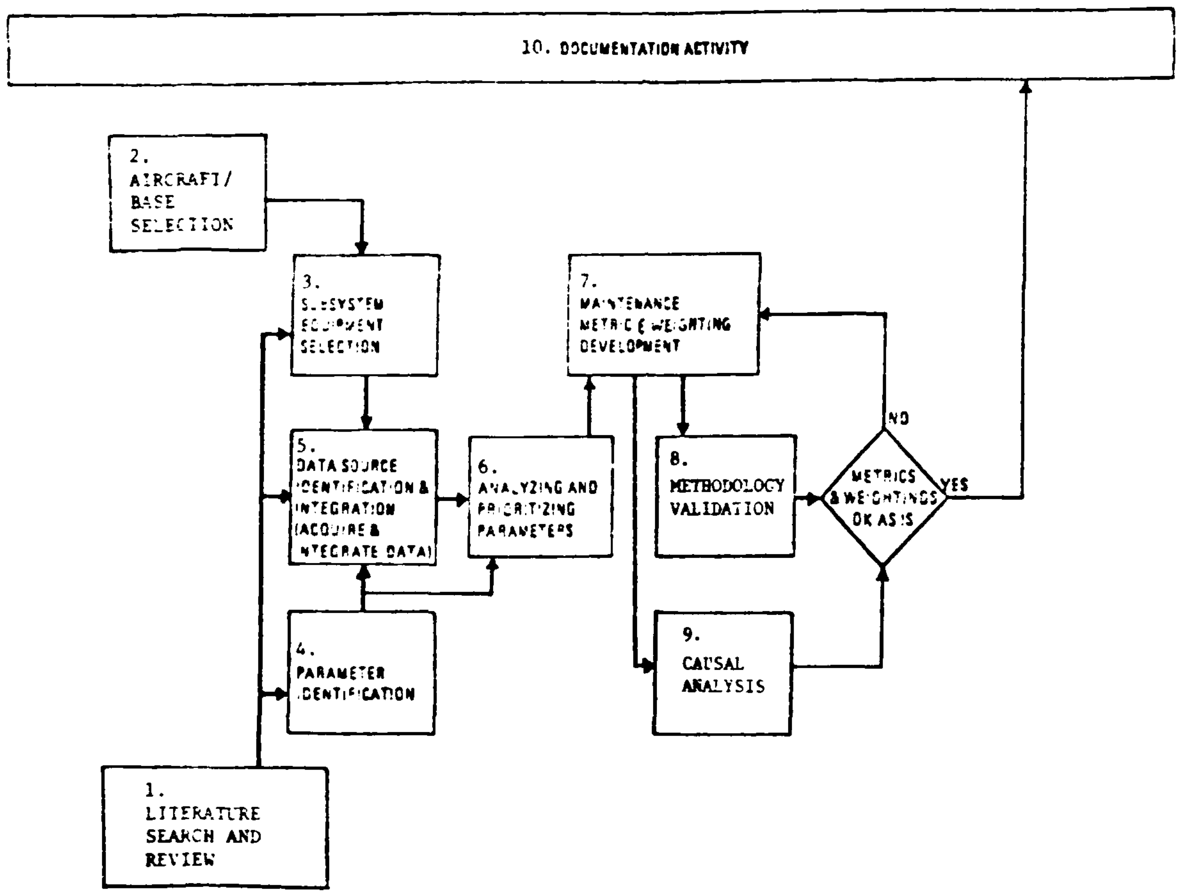


FIGURE 2 SEQUENCE OF MAJOR TASKS

3. <u>Select Subsystem Equipment</u>
The matrices of equipment by current Air Force aircraft type were developed and used to select a representative cross-section of subsystem equipment for the 19 common aircraft subsystems.

4. <u>Identify Maintenance Impact Parameters</u>
This effort identified the equipment, operational, and environmental parameters that might significantly impact maintenance resource demand on the selected subsystem equipment. Phases I and II identified and tested a broad range of potential maintenance impact parameters. Phase III utilized only those parameters with significant maintenance impact based on the experience of Phases I and II.

5. <u>Identify and Integrate Data Sources</u>
This task identified, acquired, and integrated the data base on the equipment selected in (3) for the related parameters being considered in (4). For Phase III, separate data bases were assembled for bombers, cargo/transports, and fighters.

6. <u>Analyze and Prioritize Parameters</u>
These analyses prioritized the collected aircraft data to define and test relationships between the study parameters and maintenance demand rates. Parameters with significant impact on maintenance demand rates were used as source data for Task 7.

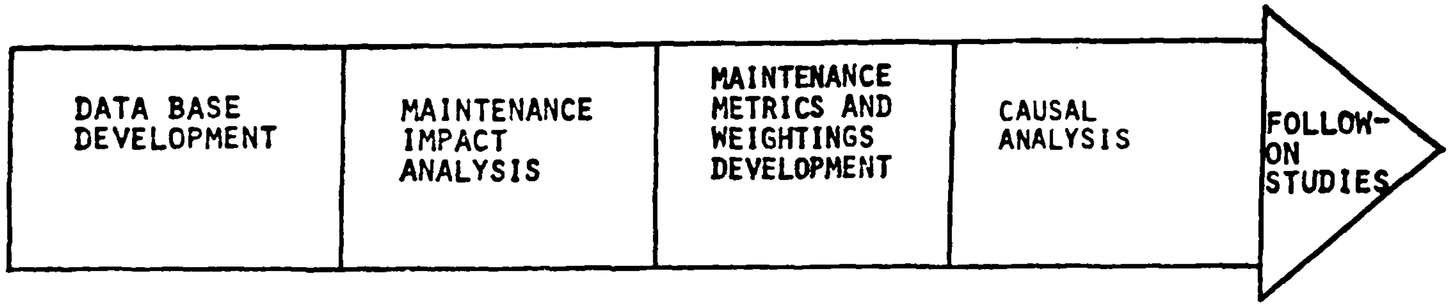
7. <u>Develop Maintenance Metric Models</u>
These metrics quantified maintenance demand rates in accordance with variations in equipment design parameters. Weighting factors were incorporated in the metrics models to adjust operational and environmental impacts on maintenance demand rates. Four maintenance demand rate estimating models were developed for each aircraft subsystem; i.e., equipment, operations, environmental, and composite.

8. Validate Maintenance Metrics Methodology
Demonstrated validity of methodology through series of LCOM simulation comparative and sensitivity analysis experiments.

9. Analyze Developed Metrics Models
These analyses investigated counterintuitive logic within the resulting metrics models. Underlying causes for model anomalies were defined where possible.

10. Prepare Documentation
Users manuals (cargo/transport, bomber, and fighter) and this final report provide the material necessary to transition the program to an operational status. In addition, the study data base and Phase I and II interim documentation is available for examination by the Air Force user community at the Logistics and Human Factors Division, Wright-Patterson Air Force Base, Ohio.

Figure 3 presents an overview of the study activities and resulting products that are available and useful for the user community.



PRODUCTS	PRODUCTS	PRODUCTS	PRODUCTS
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FIGURE 3 STUDY ACTIVITIES AND PRODUCTS BY MAJOR TASKS

2.0 STUDY DATA BASE

The data base from which the Phase III maintenance metrics were developed is composed of three major blocks:

1. Data on related research, which provided historic input for study planning, aircraft/equipment and relevant study parameter selection. This information was gathered during study Phase I and is documented.[2]

2. Data on maintenance results for aircraft equipment. These data were obtained from the existing computerized Air Force data systems in accordance with Air Force Regulation (AFR) 66-1 Maintenance Data (D056E data tapes) and AFR 65-110 Vehicle Performance Data (C033B datas tapes), and are described in paragraph 2.4.

3. Data on possible causes for aircraft maintenance demand. These data were obtained from on-site surveys at the individual Air Force bases in the Phase III study sample. These data are described further in paragraph 2.4.

The data base was developed around the selected aircraft/base combination (described in paragraph 2.1), the selected subsystem equipments (described in paragraph 2.2), and the selected study parameters (described in paragraph 2.3).

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2. Donald K. Hindes, et. al., Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems. Boeing Aerospace Company document, D194-10089-1, Revision A, Analysis and Evaluation, February 1980.

2.1 AIRCRAFT/BASE STUDY SAMPLE

For Phase I, a sparse sample of 9 aircraft/Air Force base combinations was selected to explore the feasibility of maintenance metrics development. This sample covered the range of aircraft types in current use and the range of basing environments in which the Air Force operates.

For Phase III, a representative sample of cargo/transport aircraft/Air Force base combinations was selected for each of the generic aircraft classes studied (bomber, cargo/transport, and fighter) to include sufficient cases for valid statistical analysis test and inference. In addition, the selected sample encompassed a representative range of operational environments. Table 1 lists the aircraft/base data cases from which the Phase III maintenance metrics were developed. Note that the Phase III sample includes the case sample selected for the Phase I/II feasibility study. Figure 4 illustrates the aircraft/base selection process, as well as equipment selection process discussed in paragraph 2.2.

2.2 AIRCRAFT SUBSYSTEM/EQUIPMENT SAMPLE

During Phase I/II, 30 representative, "high driver" pieces of equipment within 19 common aircraft subsystems were selected for maintenance metric development. These same items were used for the Phase III study. These common subsystems generate the major portion of aircraft maintenance demands exclusive of aircraft-model-unique subsystems such as ordnance stores. Table 2 lists the selected subsystem/equipment sample.

2.2.1 DEVELOP SUBSYSTEM/EQUIPMENT SELECTION CRITERIA

The initial subsystem/equipment selection criteria were developed early in the study and were expanded during the accomplishment of the literature review. The selection criteria utilized during the actual subsystem equipment selection process are as follows:

1. Equipment selected should be functionally representative of a wide cross-section of aircraft applications and use environments.

TABLE 1 - LIST OF CANDIDATE PHASE III STUDY AIRCRAFT AND BASES BY GENERIC CLASS (BOMBERS, TRANSPORTS, FIGHTERS)

BOMBERS

ACFT. M-D-S	A.F. COMMAND	A.F. BASE	AREA ENVIRO
B-52D	SAC	MARCH AFB, CA.	HOT/DRY
		CARSWELL AFB, TX.	HOT/DRY
		DYESS AFB, TX.	HOT/DRY
*B-52G	SAC	MATHER AFB, CA.	HOT/DRY
		*FAIRCHILD AFB, WA.	HOT/COLD/DRY
		SEYMOUR JOHNSON AFB, S.C.	HOT/WET
		ROBINS AFB, GA.	HOT/WET
		GRIFFIS AFB, N.Y.	COLD/WET
		LORING AFB, ME.	COLD/WET
B-52H	SAC	ELLSWORTH AFB, S.D	COLD/DRY
		GRAND FORKS AFB, N.D.	COLD/DRY
		MINOT AFB, N.D.	COLD/DRY
*FB-111A	SAC	PEASE AFB, N.H.	COLD/WET
		*PLATTSBURGH AFB, N.Y.	COLD/WET
		BOMBER TOTALS	
4	1	14/14 (Conus)	

CARGO/TRANSPORTS

ACFT. M-D-S	A.F. COMMAND	A.F. BASE	AREA ENVIRO
*KC-135A	SAC	MARCH AFB, CA.	HOT/DRY
		CARSWELL AFB, TX.	HOT/DRY
		DYESS AFB, TX.	HOT/DRY
		MATHER AFB, CA.	HOT/DRY
		*FAIRCHILD AFB, WA.	HOT/COLD/DRY
		SEYMOUR JOHNSON AFB, S.C.	HOT/WET
		ROBINS AFB, GA.	HOT/WET
		GRIFFIS AFB, N.Y.	COLD/WET
		LORING AFB, ME.	COLD/WET
		ELLSWORTH AFB, S.D.	COLD/DRY
		GRAND FORKS AFB, N.D.	COLD/DRY
		MINOT AFB, N.D.	COLD/DRY
		PEASE AFB, N.H.	COLD/WET
		PLATTSBURGH AFB, N.Y.	COLD/WET
*C-141A	MAC	NORTON AFB, CA.	HOT/DRY
		*TRAVIS AFB, CA.	HOT/DRY
		MC CHORD AFB, WA.	MILD/WET
		CHARLESTON AFB, S.C.	HOT/WET
		MC GUIRE AFB, N.J.	MILD/WET
C-130E	MAC	LITTLE ROCK AFB, ARK.	HOT/COLD/WET
		POPE AFB, N.C.	HOT/COLD/WET
	MAD	MILDENHALL AB, ENG	MILD/WET
	MAD	RHEIN-MAIN AB, W.GERM.	MILD/WET
C-5A	MAC	TRAVIS AFB, CA.	HOT/DRY
		DOVER AFB, DEL.	MILD/WET
		TRANSPORT TOTALS	
4	2	25/23 (Conus) 2 (Europe)	

FIGHTERS

ACFT. M-D-S	A.F. COMMAND	A.F. BASE	AREA ENVIRO
A-7D	TAC	ENGLAND AFB, LA.	HOT/WET
*A-10A	TAC	*DAVIS MONTHAN AFB, AZ.	HOT/DRY
		*MYRTLE BEACH AFB, S.C.	MILD/WET
	AFE	BENTWATERS AB, ENG.	MILD/WET
F-4E	TAC	GEORGE AFB, CA.	HOT/DRY
		HOMESTEAD AFB, FLA.	HOT/WET
		MOODY AFB, GA.	HOT/WET
	AFE	SPANGDAHLEM AB, W GERM.	MILD/WET
	AFE	RAMSTEIN AB, W GERM.	HOT COLD/WET
	AFE	HAHN AB, W GERM.	COLD/WET
	TAC	SEYMOUR-JOHNSON AFB, S.C	HOT/WET
F-5E	AFE	ALCONBURY AB, ENG.	MILD/WET
*F-15A	TAC	*LUKE AFB, AZ.	HOT/DRY
		LANGLEY AFB, VA	MILD/WET
		EGLIN AFB, FLA.	HOT/WET
		HOLLOMAN AFB, N.M.	HOT/COLD/DRY
	AFE	*BITBURG AB, W GERM.	MILD/WET
	AFE	CAMP NEW AMSTERDAM, NETH	MILD/WET
F-16A	TAC	HILL AFB, UT.	COLD/WET
F-111A	TAC	MOUNTAIN HOME AFB, ID.	HOT/COLD/DRY
F-111D	TAC	CANNON AFB, N.M.	HOT/COLD/DRY
F-111E	AFE	UPPER HEYFORD AB, ENG	MILD/WET
F-111F	AFE	LAKENHEATH AB, ENG	MILD/WET
		FIGHTER TOTALS	
10	2	23/14 (Conus) 9 (Europe)	

* AIRCRAFT/BASES USED IN PHASE I AND II STUDY EFFORTS

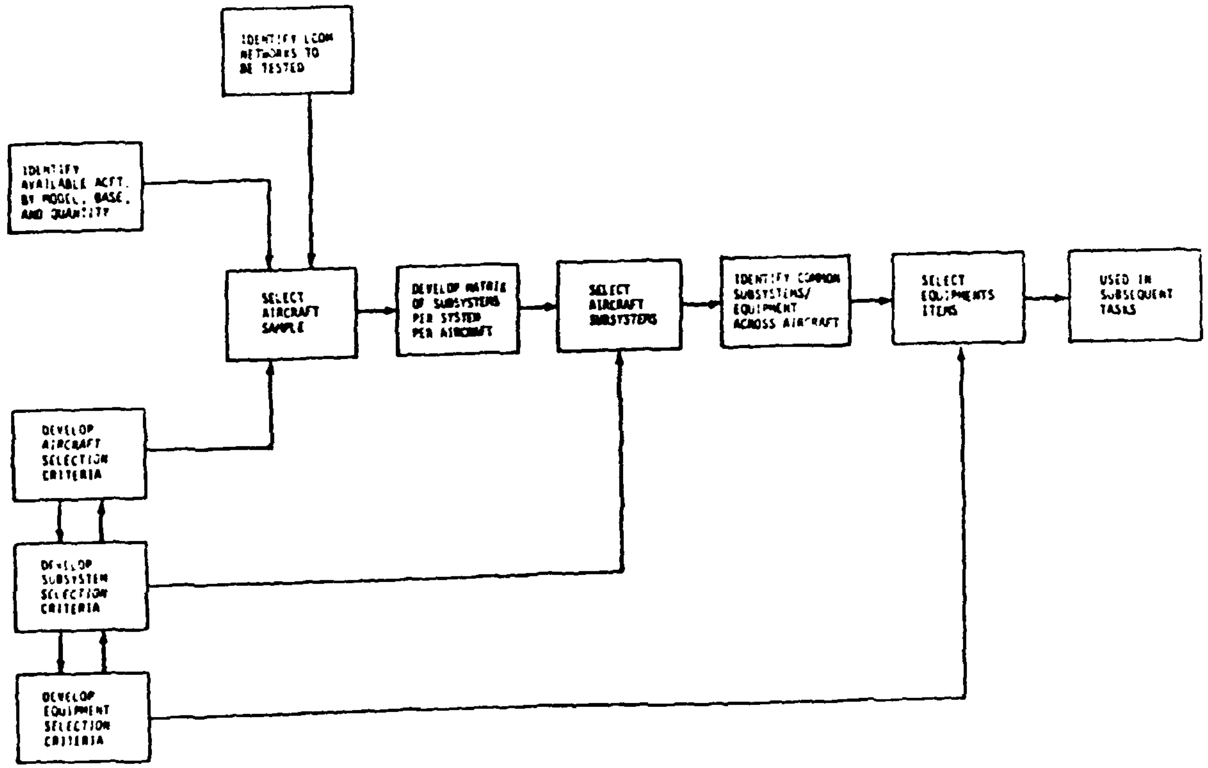


FIGURE 4 STUDY SAMPLE SELECTION PROCESS

TABLE 2 SUBSYSTEM/EQUIPMENT SAMPLE

(Air Force Work Unit Code Nomenclature)

SYSTEM NO.	SUBSYSTEM	EQUIPMENT
11	Airframe	Radome Windshield Wing
12	Interior Fittings	Crew Seat
13	Landing Gear	Wheel & Tire Brakes
14	Flight Controls	Stabilator Rudder Flaps
23	Propulsion	Complete Engine
41	Environ. Control	Moisture Separator
42	Electric Power	Generator
44	Lighting	Anti-Collision Lights Landing/Taxi Lights
45	Hydraulics	Pump
46	Fuel	Internal Tanks
47	Oxygen	Oxygen Regulator LOX Converter
49	Miscellaneous	Engine Fire Detector
51	Instruments	Flight Indicators Air Data System Horizontal-Situation Indicator
52	Autopilot	Autopilot System
63	UHF Comm. System	R/T Units
65	Iff System	IFF System
71	Radio Navigation	Inertial Navigation Set Instrument Landing Set TACAN Set
73	Bomb Nav. System	Attitude Heading Ref. Set
74	Radar Nav. System	R/T Units

2. Equipment selected should represent a wide variation in type; i.e., design technology (new-old), electrical/mechanical, parts count/complexity, maturity states, testability, and usage.

3. Packaging and design technology must be projectable into the future to prevent obsolete technology from unduly biasing statistical relationships which will be used for future predictions.

4. Equipment must be mature enough for data samples to be taken beyond the learning curve period, yet include relatively new as well as old equipment.

5. Equipment must have a statistically valid population of operational units in use.

6. The equipment must have sufficient historical data available for valid analysis.

7. Equipment selected should represent a significant percentage of the total maintenance resources expenditure demands; i.e., maintenance manhours, failures, removals, costs, etc.

8. Equipment should be of a nature such that factors other than just flying hours may contribute to their reliability/maintainability characteristics.

2.2.2 IDENTIFY SUBSYSTEM/EQUIPMENT APPLICATIONS BY TYPE AIRCRAFT

The next logical process was to develop an aircraft versus subsystem application matrix identifying the aircraft subsystems. This was accomplished by detailed review of each system in the applicable aircraft work unit code (series -06) technical orders. During this review for Phase I/II, 663 individual equipment items were examined and hundreds more were examined for the added aircraft models studies in Phase III (the B-52D, B-52H, C-130E, C-5A, A-7D, F-4E, F-5E, F-16A, and F-111A, D, E, and F aircraft were new items for Phase III).

2.2.3 SELECT SUBSYSTEM EQUIPMENT FOR PHASE III

Utilizing the equipment identified in Phases I and II, the following sequential step-by-step subsystem/equipment selection process was accomplished for the Phase III refined study.

1. Eliminated those systems/subsystems that showed up on less than five of the study aircraft.

2. Utilized the subsystem set (30 items) from 19 subsystems identified in Phase I/II.

3. Identified the functionally equivalent subsystems or similar equipment groupings within the new study aircraft.

4. Identified and listed all work unit codes (at the four or five-digit level as appropriate) for each of the subsystem/equipment functional groupings identified in 2 and 3 above.

5. Determined the number of failures reported against each of the work unit codes within each of the subsystem functional groupings from 2 and 3 above.

6. Totaled the number of failures within each subsystem functional grouping and computed what percentage of the subsystem functional grouping total the failures for each work unit code represented.

7. Selected those work unit code(s) within each subsystem functional grouping, for each aircraft, that represented the top failure percentage (50% or greater) of the total failures within the subsystem.

8. Compared common functions of the subsystem equipments selected on each aircraft and made minor adjustments as necessary to ensure that functional equivalent or similar subsystem equipments were selected across each study aircraft.

2.3 PHASE III PARAMETER IDENTIFICATION

The identification and screening process for selection of maintenance impact parameters associated with the subsystem equipments relied heavily on the previous work conducted during the Phase I and II study effort. In this initial effort, the literature search and interviews with experienced engineering, maintenance, and operational personnel were utilized to identify a list of over 200 potential maintenance impact causal parameters comprising equipment design factors, operational factors, maintenance factors and environmental factors. The efficiency of Phase III was enhanced by using only those parameters that were identified as having shown significant maintenance impacts as a result of the Phase I and II analysis.

The parameters selected passed the following selection criteria:

1. Sensitivity - The parameter is sensitive to the maintenance resource demand requirements of the subsystem(s)/equipment(s) that are being studied.

2. Availability - The information necessary for use of the parameter is identifiable and available to the study team from a known source, based on need-to-know requirements.

Considering these two selection criteria, a list of 54 individual parameters (Table 3) were selected within three major categories; i.e., equipment (hardware), operations, and environmental. These parameters are measurable characteristics of the equipment design, and of the operational and geo-climatic environments within which the study equipment operates. As such, they form the body of possible causal information within the study data base. The data

TABLE 3 **LIST OF EQUIPMENT, OPERATIONS, AND ENVIRONMENTAL PARAMETERS FOR PHASE III ANALYSIS**

EQUIPMENT PARAMETERS	OPERATIONS PARAMETERS	ENVIRONMENTAL PARAMETERS
- Equipment Location	- Avg. Take-off Speed	- Base Altitude
- Equipment Weight	- Median Take-off Distance	- Runway Direction
- Equipment Volume	- Avg. Climb Rate	- No. of Snow Days
- SRU Count	- Avg. Cruise Speed	- Total Snow Fall
- Operating Temperature	- Avg. Decent Rate	- Mean Snow Depth
- Cooling Method	- Avg. Landing Speed	- No. of Rain Days
- Support Equipment Complexity	- Minimum Landing Distance	- No. of Thunder Days
- Support Equipment Reliability	- Avg. Landing Weight	- Predominant Wind Direction
- Protection Methodology	- Max. Aircraft Speed	- Days Max. Cross Winds $<$ 20 MPH
- No. of Test Points	- Max. Aircraft Ceiling	- Days Max. Cross Winds $>$ 20 MPH
- Type of Failure Problems	- Aircraft Crew Size	- Mean Temperature (Per Year)
- Inflight Squawk Verification Rate	- Avg. Cruise Altitude	- Mean Max. Temperature (Per Year)
- On/Off Cycles Per Sortie	- Total Flying Hours Per Aircraft Per Year	- Mean Min. Temperature (Per Year)
- Ground to Flight Operating Ratio	- Total Sorties Per Aircraft Per Year	- Days Min. Temperature Below 32°F (Per Year)
- Avg. Operating Time Per Sortie	- Total Landings Per Aircraft Per Year	- Corrosion Problems
- Removals To Access Other Equip.	- Average Possessed Aircraft	15
- Total No. of Installed Engines	- Average Sortie Length	
- Take-off Thrust Per Engine	17	
- Weight Per Engine		
- Volume Per Engine		
- Landings Per Tire		
- Quantity Per Aircraft		
22		

for these parameters were obtained from the on-site base surveys.

The dependent maintenance demand variable chosen as the prime measure of maintenance expenditure was MAD. The MAD was comprised of historic maintenance (D056E) data records (averaged over 3 years) for "on-equipment" action-taken codes as follows:

R - Remove and Replace	J - Calibrated - no adjustment
P - Removed	K - Calibrated - adjustment required
Q - Installed	L - Adjust
F - Repair	V - Clean
G - Repair/Replace small parts and soft goods	Y - Troubleshoot
E - Equipment checked - no repair required	Z - Corrosion repair

2.4 DATA BASE ACQUISITION

During Phase III of the study, the Phase I and II data base was expanded to include additional aircraft/base combinations as discussed in paragraph 2.1 and shown in Table 1. This ensured that sufficient data were collected to achieve a statistically valid data sample for the maintenance impact analysis of each of the 30 subsystems within each aircraft class.

This task was extremely critical for achieving the study objectives. Therefore, additional emphasis was placed on this task by dividing it into three logical subtasks:

1. Data Identification - The identification of data sources and the types of data available within each source was relatively straightforward for the Phase III effort because of the experience gained by the study team during Phases I and II. The data required for Phase III covered two main sources for collection:

   a. Headquarters AFLC/ACRAM - AFR 66-1 Maintenance Data (D056E data tapes) and AFR 65-110 Air Vehicle

Performance Data (G033B data tapes).

b. Air Force Bases - Data required for equipment, operational, and environmental parameters (Table 3) used in the Phase III study were obtained from the appropriate individual Air Force Bases (Table 1) for each study aircraft.

2. Data Acquisition - Once the aircraft types and base combinations were selected, the next logical step was to initiate the necessary coordination to obtain the required data not already available within the study resources. In obtaining the specific data, the categories could be logically separated into computer-generated information and on-site data obtainable from the individual operational bases.

a. Computer-Generated Data

(1) AFR 66-1 (D056E) - Maintenance Resource Utilization/Management Data - This system provided the maintenance experience for the subsystem equipments studies for each aircraft/base combination.

(2) G033B - Standard Aerospace Vehicle Inventory, Status, and Utilization Report System - This system provided the operational parameters necessary for various rates associated with several of the operations parameters identified in Table 3.

3. On-Site Survey - As in any data acquisition task of this magnitude, some parameters were not available through formal Air Force data systems. This required on-site visits to obtain the necessary equipment, operational, and environmental parameter data. An on-site survey was conducted to collect the equipment, operation, and environmental parameters not available through formal data systems, at each base depicted in Figure 5. It was

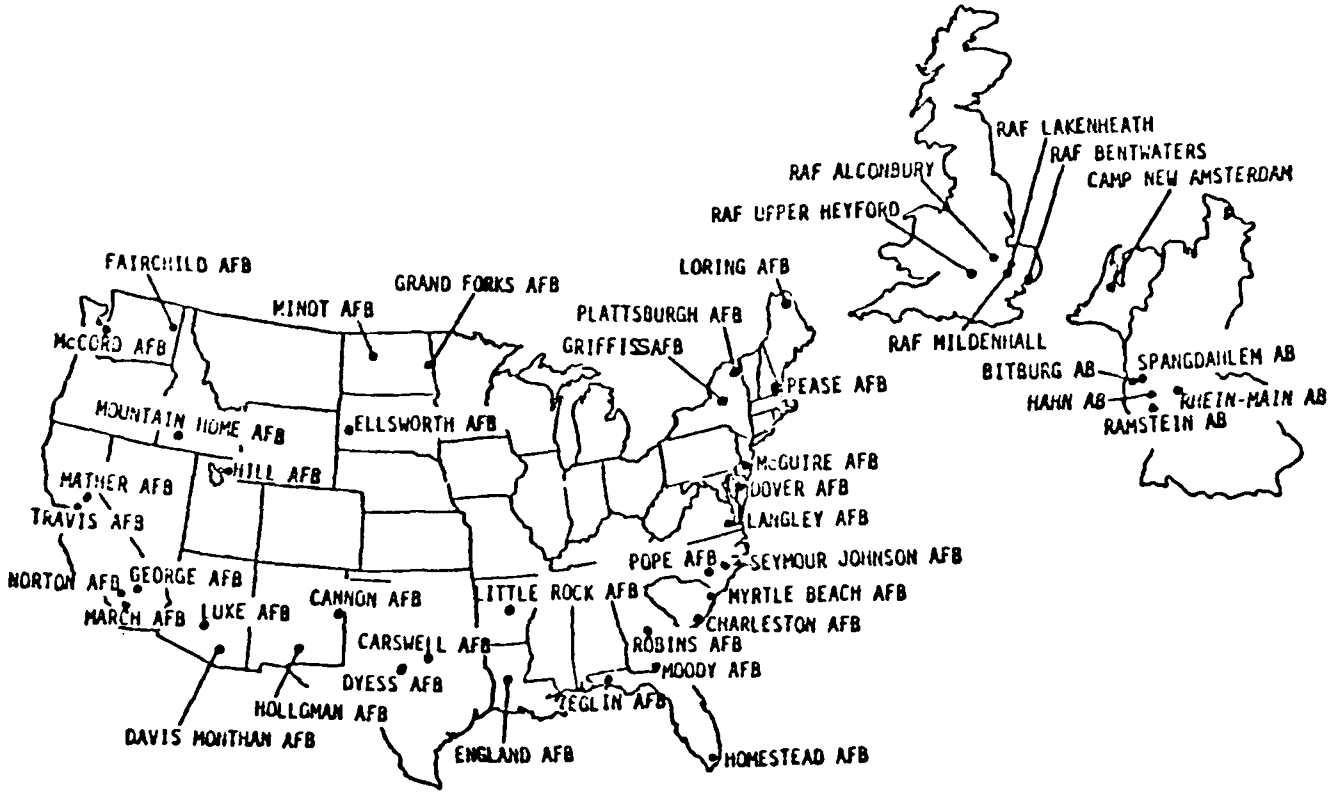


FIGURE 5 AIR FORCE BASES VISITED BY SURVEY TEAM

necessary to visit six major areas; the first and most significant was the Deputy Commander for Maintenance (DCM) office. Here a short introductory presentation was given to all functional Officers in Charge/Non-Commissioned Officers Officers in Charge (OICs/NCOICs) from whom data were required. This one-time meeting set the stage for a smooth transition of data flow. The other functional areas visited were as follows:

a. Operations - The operations or aircrew standardization organization provided the operational aircraft characteristic parameter data. Important operations-related causal insights were also provided by the interviews with these people.

b. Maintenance - The applicable maintenance organization provided the subsystem equipment characteristic and maintenance characteristic type data for all study equipments; i.e., avionics, engine, and other equipments. Also, this organization provided important causal insights for the causal analysis portion of the study.

c. Weather - The base weather station provided the environmental parameter data for that individual station. Geo-climatic maintenance causality information was also provided by this function.

d. Analysis - Monthly maintenance summaries and support general data via a Base Level Information System (BLIS) printout were obtained.

4. Data Integration - The third and final step for data base preparation was to prepare the data for the analysis accomplished in Task 6. The AFR 66-1 maintenance records (D056E) were screened and integrated into the required MAD format. The raw data from the field surveys were quantified, normalized, and collated in data matrix form for computer input and analysis.

The basic study data base in its final form consists of MAD equipment characteristics, operational characteristics, and environmental characteristics in the selected parameters for each of the 30 equipment items for each of the 62 aircraft/base data cases. The data base was divided into separate bomber, cargo/transport, and fighter data files for the statistical analysis and metrics development.

2.5 STATISTICAL SUFFICIENCY OF THE DATA SAMPLE

The bomber, cargo/transport, and fighter Phase III data samples from the standpoint of number, base location, and aircraft models were designed to give the largest sample size, the broadest range of environments, and the broadest range of equipment design possible within the time and resources available to the study project. The sample sizes for each aircraft class are considered sufficient for valid statistical analysis and data fitting. There is a high degree of confidence that the maintenance metrics developed from the study data base are accurate and credible predictors of maintenance demand. The statistical sufficiency of each of the three data samples (cargo/transport, bomber, and fighter) as measured by their non-parametric tolerance limits (single tail or one sided test) are as follows:

1. Cargo/Transport.
   For the 25 case sample, there is 90% confidence that 92% of the possible range of each datum variable is included between the low and high values recorded in the sample for each of these variables. Conversely, there is 95% confidence that 90% of each variable's possible range has been included in its sample range.

2. Bomber.
   For the 14 case sample, there is 90% confidence that 86% of the possible range of each datum variable is included between the low and high values in the sample. Conversely, there is 80% confidence that 90% of each variable's possible range has been included in the sample range of each variable. When the FB-111A cases were excluded, dropping the sample size to 12, the 90% confidence point drops

to 84% of each variable's range, and the confidence that 90% of each variables range has been included within the 12 datum points drops to 73%.

3. Fighter.

For the 23 case sample of fighter data, there is 90% confidence that 91% of each variable's range has been included between the low and high of each variable's sample range. There is 92% confidence that 90% of each variable's possible range has been included.

3.0 ANALYZING AND PRIORITIZING PARAMETERS (MAINTENANCE IMPACT ANALYSIS)

Upon acquisition and integration of the data base, qualitative quantitative analyses of these data were performed. The objective of the analyses was the detection, testing, and ranking of possible statistically useful causal relationships between the candidate maintenance impact parameters (see Table 3, Section 2) and MAD. If new strong relationships were detected for each equipment type studied, then these basic two variable parametrics could be used to build composite maintenance demand models (maintenance metrics).

The general approach divided the analysis into subtasks as shown in Figure 6. The preparation and execution of these subtasks are discussed in the following paragraphs. This approach is deliberately intended as a generalized step-by-step outline of the methodology involved so that other studies can duplicate and/or expand the methodology using widely available computerized statistical packages. The analysis as performed by Boeing Experience Analysis Center utilized a Boeing developed computer program, "PKING," which automatically combined several subtasks in order to facilitate and speed up the parametric relationship detection and testing process.

The procedure was applied to the quantification and normalization of the source data accumulated in the study data base, and the tabulation of these data into a Master Input Data File suitable for computer input and processing. Processing the data with the "PKING," cross-plotting and regression analysis program resulted in the generation of scattergrams of the MAD parameter as a function of the various candidate maintenance impact parameters in the categories of equipment, operations, and environmental. The scattergrams were screened according to the criteria of either 0.25 or better correlation coefficient of regression or -- visually apparent curvilinear relationships. Additional criteria required acceptable data point distribution and at least five data points, four of which are non-zero in both ordinate and abscissa. The screening process resulted in the rejection of most of the trial relationships tested. The remaining scattergrams with a 0.5 or better correlation coefficient were collated by aircraft class (cargo/transport, bomber, and fighter) and published as appendices to the respective aircraft class user guides (see supplements 1, 2, and 3 to this TR). These significant relationships plus the

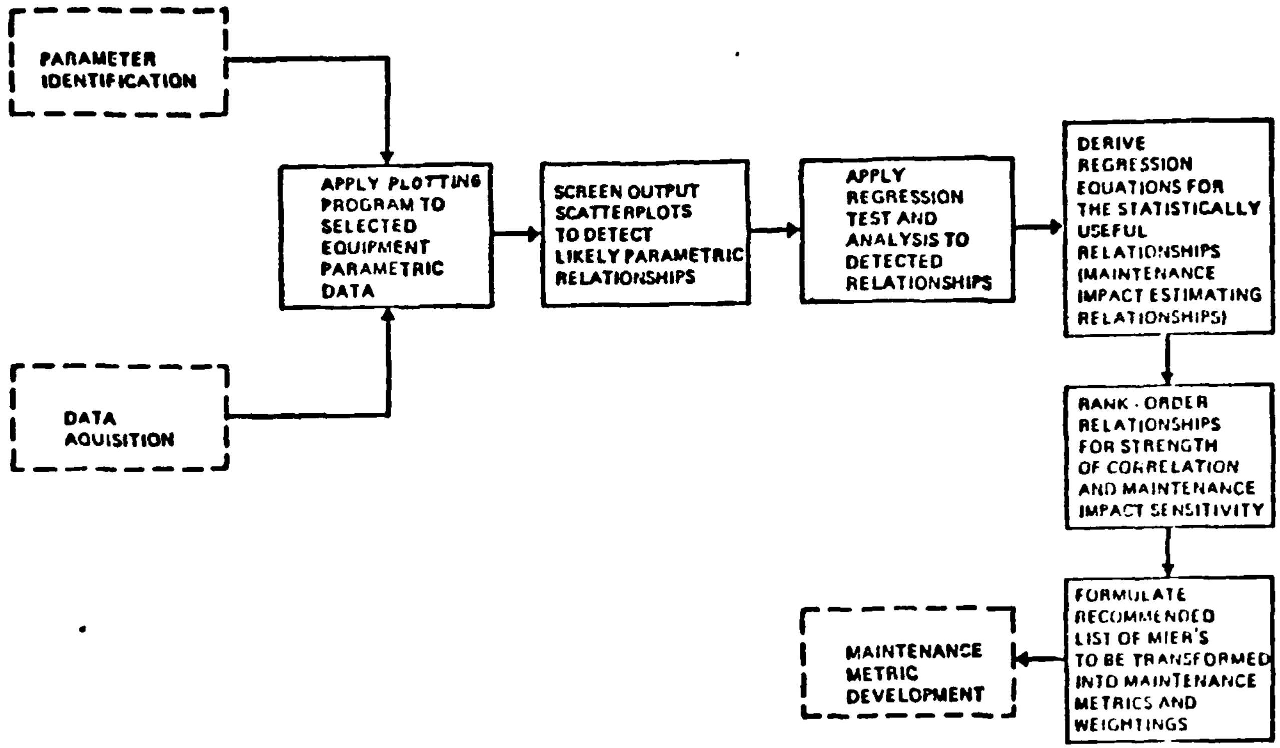


FIGURE 6 PARAMETER ANALYSIS AND PRIORITIZATION PROCESS

relationships with correlation coefficients between 0.25 and 0.5 were used as source data for the development of the maintenance metrics models.

3.1 INPUT DATA PREPARATION

Before maintenance action demand/maintenance impact parameter variable combination testing and screening could proceed, the packages of data and information gathered were sorted, quantified, and/or normalized where necessary and then tabulated in numerical data sets suitable for computer-aided cross-plotting and simple regression analysis (as discussed in detail in section 3.2). Figure 7 depicts the preliminary input data processing.

Dummy variables were created and scaled where necessary to quantify qualitative data. Quantitative data were normalized or averaged where necessary. As shown in Figure 7, the individual data packages for the items in each functional equipment group (subsystem) selected were integrated into a composite data package for each group. Subsystem equipment groups were functionally normalized across all sample aircraft and the parameter value data for each equipment item integrated into subsystem group values through a weighted average process. These composite data were next entered in the master input data records. This master file was then transformed to proper computer input format and entered in the "master file" prior to creation of magnetic disk data input files suitable for computer processing.

The format master file created was tailored for the PKING data processing program. The general process for creating the master input file is widely applicable, however, and could be used to create input files for a wide variety of data processing programs. The detailed procedure used in quantifying and integrating the "raw" data base is discussed in paragraph 3.1.1. The processed input data generated by this procedure became part of the overall study data base.

3.1.1 MASTER INPUT FILE CREATION

The field experience data gathered previously were divided into four

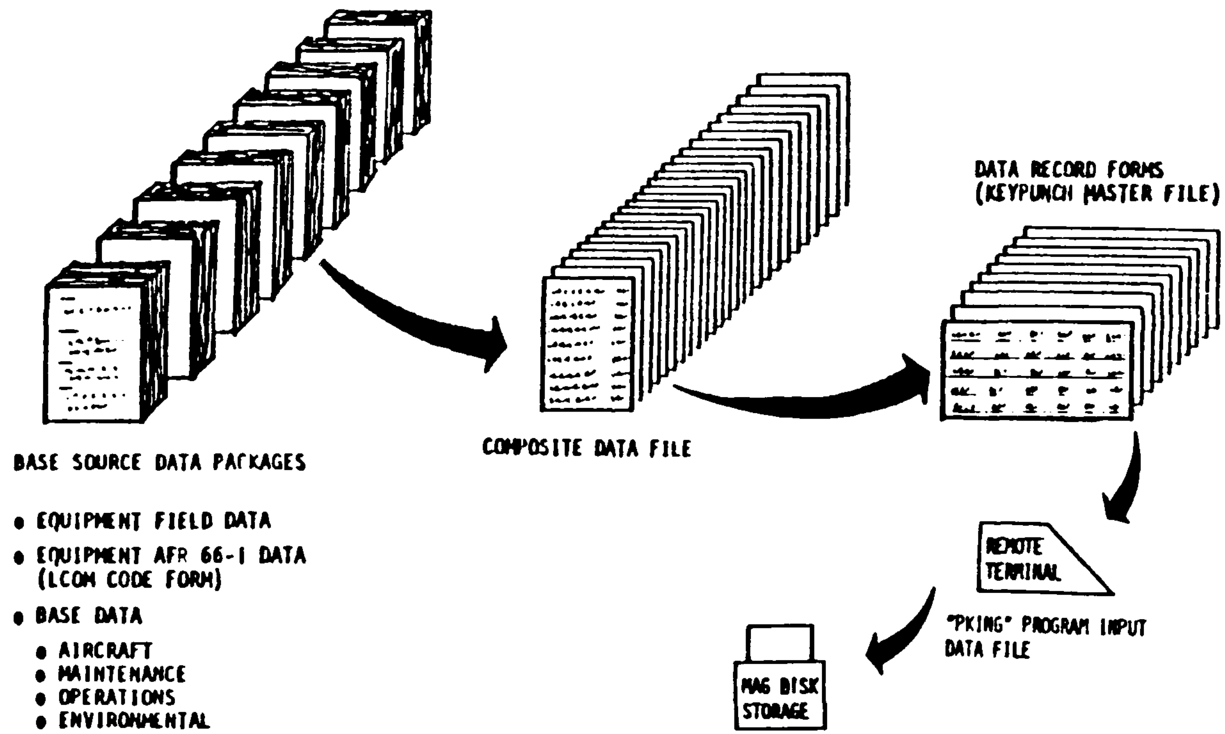


FIGURE 7 INPUT DATA PROCESSING FOR MAINTENANCE IMPACT TESTING

categories: (a) maintenance action demand parameters, (b) equipment characteristics parameters, (c) base operations characteristics parameters, and (d) base environment characteristics parameters.

Information on each parameter in the first two categories was obtained for each equipment item selected from each study aircraft at each study base. Information was obtained on an aircraft/base basis for the other two categories. This information was normalized on a subsystem basis as appropriate and entered into composite data files. The data in first two categories were gathered on each individual equipment item within each functional grouping (subsystem); therefore, data on these individual equipment items required transformation into subsystem level values. This was accomplished by a simple weighted-average method based on the relative frequency of maintenance of the equipment items comprising a particular subsystem within a particular study aircraft type. For instance, if item A and item B comprise functional subsystem C for a particular aircraft, and the MAD for item A is twice that of item B (e.g., 10 actions/unit/year vs. 5 actions/unit/year), then equipment characteristic parameter values for item A would be weighted twice as heavily as B values when calculating the composite value of subsystem C. For example, if the volume of A is 4 cubic inches and the volume of B is 7 cubic inches, the weighted average volume of subsystem C for maintenance resource demand purposes is -- $(4 + 4 + 7) \div 3 = 5$ cubic inches. This is the value entered in the composite data file and represents the average volume of items removed from subsystem C that must be dealt with by the maintenance system over the course of a year's activity. This same type of reasoning was applied to the calculation of the composite values of the other equipment characteristic parameters.

Most of the data in the data base were obtained in quantitative form. Information on a few parameters was obtained in qualitative form, however, and required quantification. Table 4 shows an example list (equipment characteristic parameters - propulsion) of the identification developed for each of the parameter input data categories. Table 4 shows the category of parameters, their type (real or scaled variable), their units of measure (if any), and the scaling conventions used for variables scaled from qualitative data. The complete parameter dimension tables for each aircraft category can be found in supplements 1, 2, and 3 to this TR.

TABLE 4 EQUIPMENT CHARACTERISTICS PARAMETERS (PROPULSION) - EXAMPLE

PARAMETER NAME	TYPE	UNITS
Total No. of Installed Engines	Real	Number/Acft.
Take-off Thrust Per Engine	Real	Pounds/10
Weight Per Engine	Real	Pounds/10
Volume Per Engine	Real	Cu. Ft./10
Density Per Engine	Real	Lb/Cu.Ft./10
No. Compressor Sections Per Engine	Real	Number
No. Compressor Blades Per Engine	Real	Number
Turbine Section Size	Real	Ft. Diam
Max Engine Combustion Temp.	Real	Degrees "C"
Max Engine Fuel Flow	Real	Lbs/Hr
Min Engine Fuel Flow	Real	Lbs/Hr
Engine Prime Depot	Scaled	Convention: 1 = OCALC 2 = SAALC 3 = Teledyne 4 = Alameda
Engine AGE Availability	Real	% Time Available When Required
Engine AGE Unreliability	Real	% Time Unreliable When Used
Engine Vibration Factors	Real	Convention: 1 = Low 2 = Medium 3 = High

3.2 DETECTION AND SCREENING OF MAINTENANCE IMPACT ESTIMATING RELATIONSHIPS (MIERs)

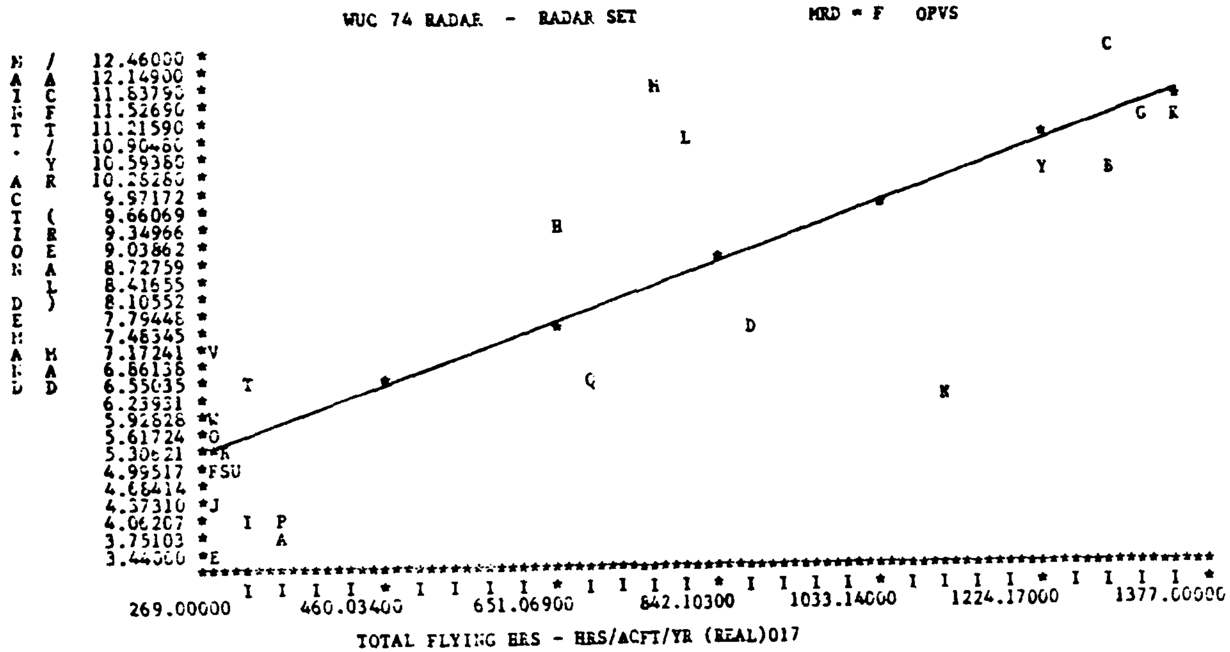
After the master input data file was transformed into suitable computer input records, the cross-plotting and least squares regression analysis computer program was applied to the data. A set of cross-plots and regression statistics was generated for each of the 30 subsystem items for each of the three aircraft classes (cargo/transport, bomber, fighter). Each set consisted of MAD as a trial function of each of the 22 equipment parameters, each of the 17 operations parameters, and each of the 15 environmental parameters. The underlying statistical characteristics assumed during the generation and screening of these trial relationships were as follows:

1. The assembled data were accurate and unbiased.

2. Each data case value was a member of or continuous normal distribution of possible values for that data case (a necessary condition for least squares regression).

These trial cross-plots and regression functions were screened for significant statistical correlation, unbiased data-point distribution, and causal reasonableness. The trial parameters found to have significant maintenance impact by this screening process are listed in this report's supplemental user guides for cargo/transports (supplement 1), bombers (supplement 2), and fighters (supplement 3). The resultant Maintenance Impact Estimating Relationships (MIERs) detected for each of the 30 subsystem items are also listed in the user guides along with a reasonable causal rationale. The detected MIERs have been divided into two groups according to their utility for the user community.

The first group consists of those MIERs with correlation coefficients greater than 0.5. These relationships are considered to have "stand-alone" usefulness for planners and designers in estimating design, operational, and environmental impacts on equipment maintenance demands. These groups of MIERs for cargo/transport, bombers, and fighters are appended to their respective user guides. Figure 8 illustrates a typical example MIER, as it is printed out from the PKING cross-plotting and regression analysis program.



YD(ESTIMATE) = M*XI + B

CORREL.COEFF.(R) = .83249
SLOPE (M) = .00562
Y INTERCEPT (B) = 3.72910

A MARCKC-135A
B NORT C-141A
C TRAV C-141A
D TRAVIS C-5A
E MATHKC-135A
F ROB KC-135A
G CHAR C-141A
H POPE C-130E
I S-J KC-135A
J FAIRKC-135A
K MCGU C-141A
L DOVER C-5A
M [illegible] C-130E
N HILL C-130E
O DYESKC-135A
P CARSKC-135A
Q L-R C-130E
R PLATKC-135A
S GEIFKC-135A
T PEASKC-135A
U LOR KC-135A
V ELLSKC-135A
W MIN KC-135A
X G-F KC-135A
Y MCORDC-141A

FIGURE 8 TYPICAL MIER CROSSPLOT

The remaining group consists of those MIERs which have passed the screening criteria for data-point distribution, visually non-random distribution, and causal reasonableness, and which have correlation coefficients between 0.25 and 0.5. These MIERs are considered to indicate definite non-random relationships between the dependent variable MAD and the subject independent variables. However, no MIER with a correlation coefficient below 0.5 explains enough of the variance of MAD to be used alone for maintenance demand estimating. Therefore, these MIERs were not directly included in the user guides. Instead, the data from which they were derived were incuded in the input data for the multiple regression model development effort discussed in the following paragraph 4.0. All cross-plots generated during the course of parameter analysis and prioritization have been filed as part of the study data base and are available for examination.

3.3 SPECIAL FINDINGS FROM THE DATA BASE ANALYSIS

During the course of analysis of the Phase III data base, two major anomalies became apparent and warranted further investigation. One concerned the sense of the correlations betweem fighter equipment MADs and usage variables such as flying hours per year. The data apparently indicated that the more the equipment was used, the less it failed. Since this seemed to go against the laws of physics, this apparent anomaly in the data was thoroughly investigated, and the results are presented in paragraph 3.3.1.

The other major anomaly affected all three classes of aircraft and concerned the sense of the correlations between wheel and tire MAD and landing gear usage variables such as landings per year. These data also seemed to indicate that the more landings made, the longer tire life to be expected. Since common sense and other statistical studies of tire life have shown the direct wear effects of landings on aircraft tires, it was apparent that something was drastically wrong with the study data as obtained from the D056E and G033B tapes. An in-depth investigation was made of this anomaly, and the detailed results are presented in paragraph 3.3.2.

3.3.1 FIGHTER USAGE FACTOR INVESTIGATION

When the correlation tests of fighter equipment maintenance action demand against operational parameters were being screened, a significant anomaly became apparent. In general, fighter equipment MAD was found to be negatively correlated with the usage variables sortie rate, total landings, and flying hours. Out of the 30 fighter equipment items tested, 22 indicated negative correlations between MAD and these variables. The data apparently indicated that the more the equipment was used, the less it failed. This seemed to be against the laws of physics as well as common sense; therefore, an investigation of the data was initiated. After a detailed cross-checking of the records, both the AFR 66-1 Maintenance Data Collection (MDC) System values for MAD, and the AFR 65-110 Status and Utilization Reporting System values for the usage variables were found to be accurate and complete. The anomaly was due to other underlying causes.

To gain some insight into these causes, various aggregate tests were performed on the fighter equipment data. Aggregate MAD per aircraft was ranked by model (F-5E, A-10A, F-4E, etc.) and plotted against by-model rankings of operational variables 014, sortie length; 015, total sorties; 016, total landings; and 017, total flying hours. Clear aggregate functional trends emerged from these analyses as follows:

1. Maintenance Demand = +F (Sortie Length)
2. Total Sorties Achieved = -F (Maintenance Demand)
3. Total Landings = -F (Maintenance Demand)
4. Total Flight Hours Achieved = -F (Maintenance Demand)

From these results a working hypothesis was formed:

If a key MAD causal parameter is --
"Continuous Operating Time,"

Then it follows that --
The longer the required sortie length, the higher the expected MAD and maintenance downtime.

The longer the maintenance downtime -
The fewer sorties that are achieved, the fewer landings that are made, and the fewer flight hours that are achieved.

The foregoing statements are reasonable in light of typical flying scheduled in fighter wings. In general, commands using fighter aircraft try to fly as much as possible within the constraints of maintenance downtime and adverse weather. The implication of this opeartional policy is that flight hours, sortie rate, and landings are dependent of maintenance demand, not the other way around. The fighter data sample givers evidence that this is true in that it reflects historic achieved flying hours and sortie rates which may possibly be driven by historic maintenance downtime. Due to resource constraints, other hypothesis to explain this apparent anomaly were not investigated. Clearly the finding warrants further study to determine the causal factors that could impact fighter aircraft MAD.

In light of the preceding working hypothesis, "Required Sortie Length" will be valid predictor for fighter MAD in new aircraft/basing situations while "Sortie Rate" and "Flying Hours" based on historic values may not be reliable. Therefore, although the hypothesis is unproven, it was used as a basis for deleting fighter Sortie Rates, Landings, and Flying Hours from the maintenance metrics development process, except for some systems with overriding considerations, such as landing gear and wings.

3.3.2 AIRCRAFT TIRE FAILURE DATA INVESTIGATION

During the data analysis effort of the Phase III study, it became apparent that landing gear maintenance action demand data for all three types of aircraft studies (cargo/transport, bombers, and fighters) were in conflict with common sense as well as previous tire life studies.

The MAD on wheels and tires were found to be negatively correlated with the usage indicators, such as total landings and flying hours. In other words, the data indicated that more landings resulted in longer tire life and less failures. A likely hypothesis was that the MAD data were incorrect or incomplete. Consequently, a detailed investigation and analysis of this anomaly was initiately with a twofold objective:

1. Find the cause of the anomalies in the data samples.

2. Choose the best wheel and tire MAD parameter data for maintenance metric development for each type of aircraft.

The wheel and tire MAD which showed the anomaly was composed of maintenance actions recorded against the wheel and tire work unit codes in the AFR 66-1 Maintenance Data Collection (MDC) system. These included the tire shop actions: "Not Repairable This Station," and "Condemn" for each of the 46 bases visited during the Phase III study. These action records were supposed to give an accurate count of wheel and tire maintenance demand since tires are depot repairable only. These were the data that required investigation.

As a first step, the "as received" MDC wheel and tire data were examined on a month-by-month basis for the 3-year historic time slice used to normalize the study data base. It was noted that some bases did not record any tire NRTS or condemn actions for the entire 3-year period. Others had only a few actions recorded against the wheel and tire work unit codes. These AFR 66-1 MDC records were then cross-checked at the local level by contacting the individual bases' Maintenance Production Analysis offices for their local listings of tire NRTS and condemnation actions. Their listings confirmed the values in the AFR 66-1 MDC listings. The data problem was therefore assumed to be at the base tire shop level.

From the tire shops of the subject bases, we found out the following: When a wheel and tire are removed from the aircraft, a Remove (P) or Remove and Replace (R) action, with appropriate "How Malfunction" code, is documented on an Air Force Technical Order (AFTO) Form 349, Maintenance Data Collection (MDC) Record. This is usually documented against the failed item (wheel component or tire component).

After the tire has been dismounted in the shop, it is either sent to supply for recapping or condemned to salvage. All these actions and times are recorded on the AFTO-349 form but now under the Shop Support General Work Unit Code (WUC) 09000. The tire has now lost its identity and there will be no NRTS actions against the tire WUC in the AFR 66-1 data bank. According to AFR 66-1, the shop should have generated another AFTO-349 form against the tire, showing the appropriate NRTS action. However, this is done inconsistently, or not at all, because all the times and actions spent on the tire have been accounted for in other paperwork. What makes this problem so difficult is that the documentation procedures are not consistent from base to base. Therefore, a more accurate and consistent way to count wheel and tire maintenance actions is to tabulate P and R action codes recorded against the wheel and tire work unit codes. Unfortunately, this method is not always consistent among the different commands so an alternative, more subjective data set was also examined and analyzed for wheel and tire maintenance demand.

During the base visitation phase of the metrics contract, the base tire shops were asked to furnish estimates of how many tires were NRTS condemned in an average month. These subjective experience data were used as a cross-check of the MDC data sample. After examining these data and comparing them with the "P and R" data set, some inconsistencies were noted at several bases. These were probably due to the uneveness of both the way the shop estimates were made (everything from offhand "guesstimates" to detailed shop record counts), and the inconsistencies in the recording of P and R actions against the tire WUC. Both data sets had good and bad characteristics for determining actual wheel and tire maintenance action demand. Further analyses and tests were performed on both the "P and R" and "subjective" data sets in order to select the best wheel and tire MAD parameter for each class of aircraft. For the cargo/transport and bomber types, the MDC "P and R" data set proved to be best for wheel and tire MAD; whereas for fighters, the "subjective" data were used for wheel and tire MAD.

4.0 DEVELOPMENT OF MAINTENANCE METRICS AND WEIGHTINGS MODELS -

The next step in the attainment of study objective was the development of new comprehensive prediction and estimation models for maintenance action rates from the field experience and analytical data base accumulated by the first five study tasks. The objective of this model development effort is the improvement of the estimation techniques currently used to predict the maintenance metrics of emerging weapon systems and/or new basing concepts. This effort was originally intended to utilize the design, packaging environment, and use characteristics of the equipment items studied to develop statistical mathematic or parametric models for the estimation of the resource demands of each study subsystem separate from operational or environmental factors. Then it was intended to develop statistical weighting factors with which to modify model estimation results to compensate for specific aircraft basing concepts operational and environmental conditions. It was found to be more accurate and efficient to include the operational and environmental factors in the initial statistical analysis. Therefore, these tasks were combined into one effort.

Maintenance metrics model development was divided into three distinct but similar subefforts. Maintenance metric models were developed in separate efforts specifically tailored for cargo/transport, bomber, and fighter aircraft equipment, respectively.

Multiple regression MAD estimating models have been developed for each of the 30 subsystem items for each of the three classes of aircraft. Four regression equations were developed for each item to facilitate MAD estimating efforts within the user community. The first three equations utilize either equipment parameters, operational parameters, or environmental parameters, respectively. These models are intended to be used to provide the best available MAD estimate when the potential user has access to or knowledge of only one or two of the three types of parameters. For instance, a planner who needs a maintenance demand estimate in a new basing situation and has access to the planned operational scenario and/or the new base environment but does not know the aircraft equipment characteristics can use the operations models or the environment models to obtain the estimate. Conversely, a designer who knows the aircraft equipment characteristics but does not know the basing situation within which the aircraft is to be used can estimate maintenance demand with the equipment model.

The fourth regression equation for each item combines the most significant equipment, operational, and environmental parameters within one model. These composite models are preferred for computing MAD estimates since use of all three parameter types yields a more well-rounded, accurate estimate of actual field experience maintenance demand. It is therefore recommended that the user community utilized the composite models whenever possible.

4.1 MODEL DEVELOPMENT

The procedure used to develop the MAD estimating models is illustrated in Figure 9. The data from which the significant MIERs for each of the 30 items were derived (refer to paragraph 3.0) were merged into input data sets of significant equipment, operational, and environmental parameters (three data sets for each equipment item). Packages of data sets were assembled for each of the three aircraft classes. These data sets were then operated on with an interactive, stepwise, multiple regression computer program to yield the three types of generic models (equipment, operational, and environmental). The parameters that survived in each item's generic models were, in turn, merged into composite data sets for input into the stepwise program. This procedure yielded a composite model for each of the 30 equipment items for each of the three types of aircraft: cargo/transport, bombers, and fighters.

The form of the composite models is as follows:

$$\begin{aligned} MAD = {} & A+(B_1 \text{ Equip Param}_1 + \ldots + B_m \text{ Equip Param}_m) + \\ & +(C_1 \text{ Opnl Param}_1 + \ldots + C_n \text{ Opnl Param}_n) + \ldots \\ & \ldots + (D_1 \text{ Environ Param}_1 + \ldots + D_p \text{ Environ Param}_p). \end{aligned}$$

The generic and composite input data sets from which the MAD estimating models were derived form part of the basis maintenance metrics data base. Figure 10 illustrates a typical example of a composite regression model developed during this effort. Complete listings of the generic and composite models for cargo/transport,

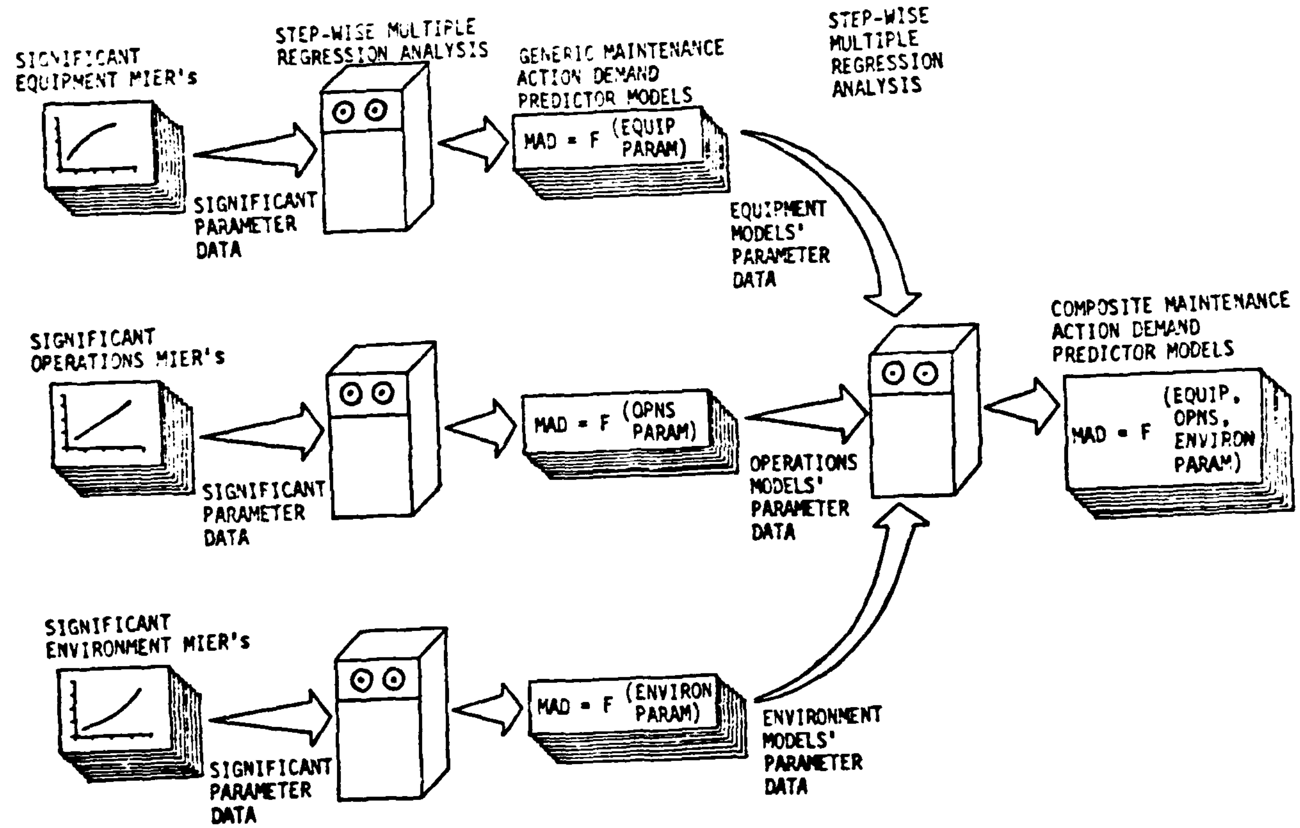


FIGURE 9 MAINTENANCE METRICS PREDICTOR MODEL DEVELOPMENT PROCESS

(Compute estimated maintenance action demand (EMAD) per unit per year as a function of significant equipment, operational, and environmental parameters)

Form of model (multiple regression estimating equation):

$$EMAD = A+(B_{e1}EQ_{e1}+\ldots B_{en}EQ_{en})+(B_{o1}OP_{o1}+\ldots B_{on}OP_{on})+(B_{n1}EN_{n1}+\ldots B_{nn}EN_{nn})$$

Equipment Item: SYSTEM 44, ANTI-COLLISION LIGHTS   DATA SET: FCOM13

Regression Equation: EMAD = +4.238 + 3.052(S16) - 0.023(Ø07) - 0.002(E06)

Where --	S16 = REMOVALS TO ACCESS OTHER EQUIPMENT	Computed T = +5.753
	Ø07 = AVERAGE LANDING SPEED	Computed T = -2.332
	E06 = AVERAGE RAIN DAYS PER YEAR	Computed T = -1.101

Adjusted Multiple Correlation Coefficient = 0.860

FIGURE 10 EXAMPLE OF COMPOSITE MAINTENANCE METRICS MODEL bombers, and fighters can be found in the respective user guides (supplements 1, 2, and 3 to this technical report).

The statistical characteristics assumed for model development were as follows:

1. Each major independent variable appearing in each model equation is unrelated to other major independent variables in the model.

2. The range of values represented by the data samples used encompassed essentially the full range of possible Air Force-wide values for equipment, operational, and environmental characteristics for cargo/transports, bombers, and fighters.

4.2 MODEL RATIONALE

The generic and composite Maintenance Metrics and Weightings regression equations developed for the study were based on a sampling of the critical equipment items in each aircraft subsystem. Critical equipments are considered to be those items (usually only one or two), within a subsystem, which drive the maintenance resource demands of that subsystem and may be used to represent the total subsystem without serious degradation of maintenance metrics analysis results. Critical equipments rather than total subsystems were used for maintenance metrics development because the far greater time and resources required for the data gathering and analysis of each item in each subsystem could not be justified in terms of the increased accuracy of the metrics developed. (Section 2 of this report discusses subsystem equipment selection and data acquisition.) Therefore transformation of the outputs of the regression models (partial subsystem MAD estimates) must be performed to prepare total subsystem MAD estimates. This is accomplished through the utilization of an actual sample of historical maintenance action demand data for the subsystems (or similar subsystems, if equipment is new) being analyzed and simulated. These actual data are used to calculate a ratio factor of total subsystem MAD to selected equipment sample MAD. This total subsystem MAD scale factor can then be applied to the partial MAD estimates to yield total subsystem MAD estimates.

4.3 SPECIAL FINDINGS FROM MAINTENANCE METRICS MODEL DEVELOPMENT

During the course of metrics model development, certain general and specific trends and findings became apparent. One of the major objectives of the overall study was to evaluate actual usefulness of the traditional sortie rate to failure and/or flying hours to failure metrics in predicting maintenance demands of the detailed subsystems and equipment on aircraft. The study findings in this area are quite interesting in that not only have the importance of these traditional measures diminished within the statistically derived math models which were developed, but also that important differences have turned up between the various categories of aircraft. These differences seem to be due largely to the differing design, operational, and environmental regimes within which transports, bombers, and fighters operate.

The major usage parameters (sortie rate, landings, and flying hours) appear in 13 or 29 cargo/transport composite MAD estimating models. Of the 13 models containing usage parameters, six are for primarily mechanical systems and seven are for primarily electrical or avionics systems.

In the bomber aircraft category, usage parameters appear in only 10 of 30 composite models. Of these 10, 8 are avionics, and only 2 are for primarily mechanical systems. This result is rather surprising when the natural assumption would be that the mechcanical systems would be more sensitive to usage than would electronics systems. One possible explanation lies in the bomber sample used to develop the models. Many of the avionics systems on the older B-52 models contain old technology electronics, which is much more sensitive to wear-out than is the newer solid-state, integrated electronics.

For fighter aircraft, usage parameters were rarely found to be legitimate MAD causal factors. The reasons are discussed in detail in Section 3.3.1. Of the 30 equipment items, only the Identification Friend or Foe (IFF) system composite model contains sortie rate as a legitimate usage factor. Another causal parameter that also is an indication of wear-rate and stress exposure is important to the fighter MAD estimating models, however. This parameter is "sortie length," and is a factor in 11 of the fighter composite models.

In summary, it can be seen that usage factors do not, in general, drive the maintenance metrics models. This does not necessarily mean that these factors do not play a role in the maintenance demand of equipment. Rather, these results should be interpreted as indicative of relative statistical importance. During the statistical analysis of the data, other causal factors showed more statistical strength in "fitting" the data, and the conventional usage measures dropped out of the models.

Another lesson to be learned from the model development process is that reliance cannot be placed on any few strong driving causal factors to predict the demands of the diverse equipments comprising modern aircraft (as exemplified by the usage factors above). Each subsystem requires individual analysis in light of its individual design characteristics and use environment. For instance, the maintenance demand for the landing gear is strongly dependent on usage factors; while jet engines seem to be far more sensitive to operating temperature, temperature cycles, and complexity factors than to operating time or usage alone. Modern aircraft electronics MADs, on the other hand, tend to be more dependent on complexity factors (part counts) than either operating time or on-off cycles (temperature excursions).

5.0 MAINTENANCE DEMAND CAUSAL ANALYSIS

During Phases I and II model development, it was found that some of the independent regression variables and/or the polarities of their coefficients appeared to run counter to conventional experience and expectations as to the causality of maintenance demand. The appearance of this counterintuitive model logic indicated the requirement for further investigation into the actual underlying causes and mechanisms of maintenance action demands associated with design, operational, and environmental factors. In some cases, these anomalies in conventional logic appeared to be due to basic underlying variables in equipment design, usage, or environmental exposure. These causes may not be directly measurable but act to influence the maintenance metrics models through surrogate parameters in the model equations. In other anomalous cases, it was suspected that certain variables entered the regressions in counterintuitive ways because of the manner in which multiple regression analyses are mechanized.

The refined and expanded maintenance metrics and weightings models developed during Phase III (see Section 4.0) also contain occasional counterintuitive anomalies. Therefore, the focus of this effort was to explain and normalize the anomalies encountered on selected maintenance metrics models and provide a causality rationale for the parameters entering the equations.

5.1 CAUSAL ANALYSIS APPROACH

The approach taken to the causal analysis is illustrated in Figure 11. In this approach, the independent variables (model parameters) explaining each equipment item's MAD are logically linked with basic causal factors which in turn can be decomposed into elemental equipment and human stressors (underlying causes for equipment failure and/or human maintenance error). These logical linkages are in turn given credibility through the linking of supporting direct field evidence gathered during the on-site base surveys. Figure 12 portrays the relationships between the nine identified aircraft maintenance demand causal factors and the elemental aircraft equipment stressors. An example of a causal factor/field evidence linkage diagram for a typical equipment item's composite MAD estimating model is illustrated by Figure 13. Complete listings of each equipment item linkage diagram for cargo/transport, bombers,

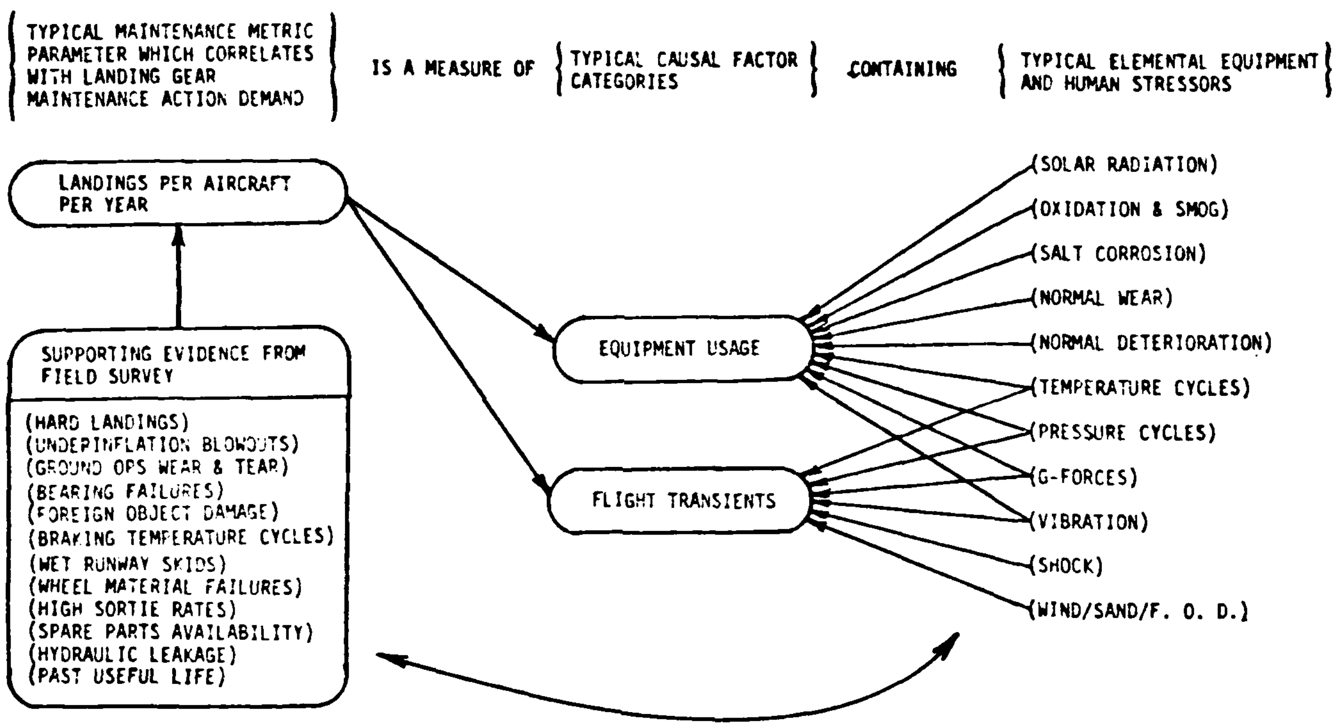


FIGURE 11 CAUSAL ANALYSIS APPROACH

CAUSAL FACTORS CATEGORIES \ ELEMENTAL EQUIPMENT & HUMAN STRESSORS	SOLAR RADIATION	HEAT (SEVERE)	COLD (SEVERE)	TEMPERATURE CYCLES	PRESSURE CYCLES	CLEAN WIND	WIND/RAIN	WIND/SNOW	WIND/DUST	WIND/SAND/F O D	HUMIDITY	WATER CONDENSATION/ LEAKAGE	ICE & SNOW	OXIDATION & SMOG	SALT CORROSION	G-FORCES	VIBRATION	SHOCK	NORMAL WEAR	NORMAL DETERIORATION	DESIGN COMPLEXITY	HUMAN ERROR
USAGE FACTORS	●			●	●									●	●	●	●		●	●		
FLIGHT TRANSIENT FACTORS				●	●					●						●	●	●				●
OPERATIONAL FACTORS		●	●	●	●		●	●	●	●	●		●	●	●	●					●	●
MAINTENANCE FACTORS	●	●	●				●	●	●	●	●		●	●	●						●	●
COMPLEXITY FACTORS																			●	●	●	●
DESIGN DEFICIENCY FACTORS				●	●							●				●	●	●	●	●	●	●
INTERNAL ENVIRONMENT FACTORS		●	●	●	●						●	●		●	●		●	●			●	
EXTERNAL ENVIRONMENT FACTORS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●							
HUMAN FACTORS	●	●	●			●	●	●	●	●	●		●								●	●

FIGURE 12 RELATIONSHIP BETWEEN MAINTENANCE CAUSAL FACTORS AND UNDERLYING STRESSORS

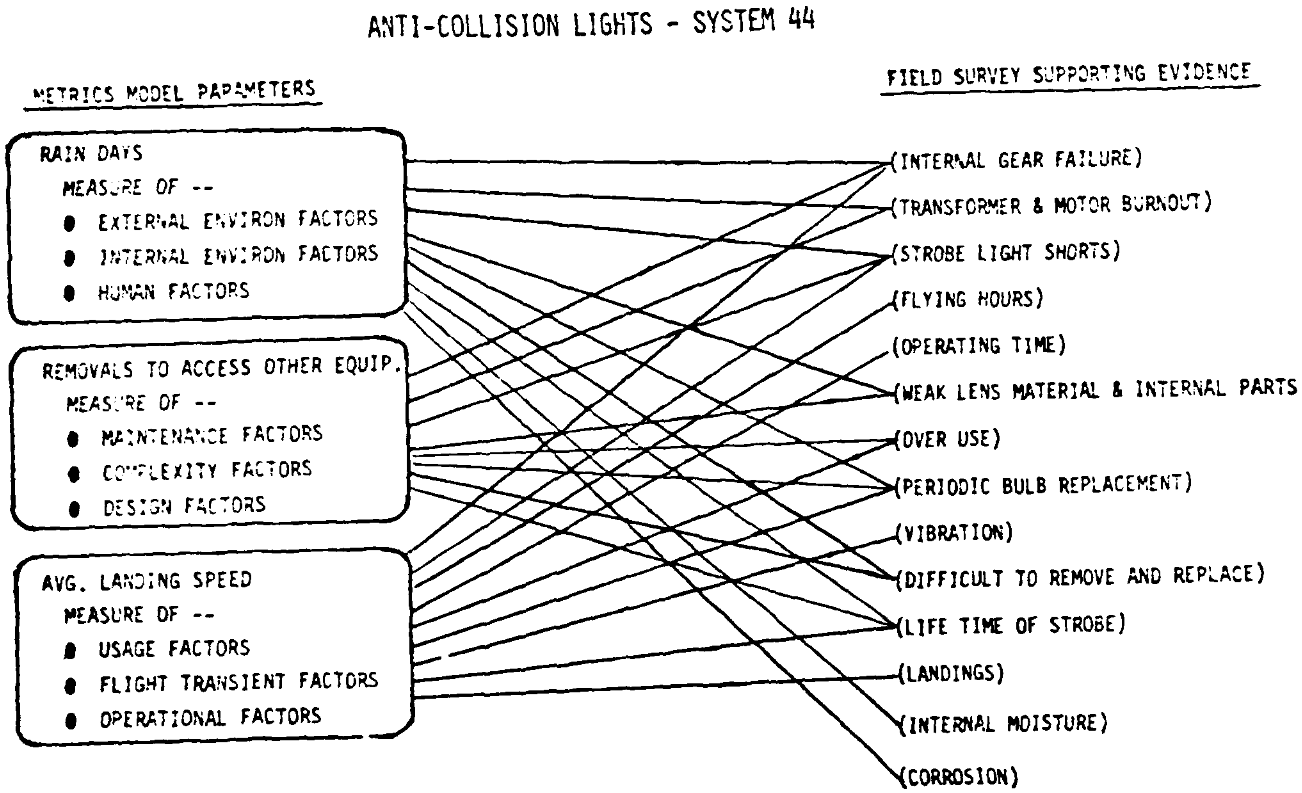


FIGURE 13 EXAMPLE QUALITATIVE CORRELATION OF METRICS MODEL PARAMETERS WITH FIELD SURVEY SUPPORTING EVIDENCE

and fighters can be found in the respective users guides (supplements 1, 2, and 3 to this technical report)..

5.2 SPECIAL FINDINGS FROM CAUSAL ANALYSIS

During the course of the base surveys and the subsequent causal analyses, certain insights were gained to the maintenance problems and underlying causes of maintenance demand in the field situation. These major insights are as follows:

1. Unrecorded Ground Operating Time. This is a major factor which escapes the present data collection systems. In the base surveys, the intent was to capture this factor in the data sample through interview methods. Gathering ground operating events at the flight line, at maintenance control, and in operations permitted computing and recording total operating times on the study equipment that are much closer to actuals than the flying hours recorded on the G033B tapes. These ground operating times turned out to be as much as three or four times the flying hours on some items of equipment. An example of how large amounts of ground time can go unrecorded can be seen in the case of Hahn Air Base, Germany. Hahn is in an area of many quick storms, fog, and other obstructions to vision. Weather aborts at the end of the runway are common. The aircraft may sit with the engine running and all systems operating for 1.0 to 1.3 hours and never fly. This extra ground time is not recorded in the common Air Force data systems. The same thing happens to a lesser extent at many other bases.

2. Maintenance And Spares. Spares shortages, long depot recycle times, and poor quality/faulty spares were common complaints from base maintenance and quality control people. This has a direct bearing on overall maintenance demand and mission readiness. An example of the sensitivity of maintenance to the depot/supply function can be seen at RAF Lakenheath, England. This location has depot repair facilities and personnel colocated at the base for critical components. This works out very well for enhancing "fully mission capable" readiness.

3. Manning. In general, all of the bases visited have sufficient total personnel but need skilled middle grades (primarily due to attrition of specialist 5-levels. The available personnel were primarily 3-levels and also 7- and 9-levels. This void definitely impacts maintenance efficiency.

4. Adverse Weather Maintenance Demand Factors. During the course of the causal analysis of the data, an interesting relationship became apparent. In general, an inverse relationship exists between MAD and all "bad" weather parameters, such as rain days, snow days, snow depth, freezing days, and predominant northwest winds. This is, the worse the weather, the fewer the maintenance action demands. This relationship exists for practically all equipment items regardless of their type or their location on or in the aircraft. A plausible explanation for this, borne out by general flying hour trends, is that there is less flying, hence less usage and less maintenance demand during adverse weather. It is also possible that maintenance performance rate is slowed by adverse weather. This is, fewer maintenance actions get done and recorded per day.

6.0 SUMMARY CONCLUSION

This technical report summarizes the final findings and conclusions of the 3-phase AFHRL maintenance metrics contact. This report is supplemented by the three users' guides which document the developed maintenance metrics and findings for (1) cargo/transport, (2) bomber, and (3) fighter aircraft respectively. It presents descriptions of methodologies, data, models, and findings developed during the study effort. The methodological descriptions and findings contained within this final report are presented in a task-oriented sequential format as follows: (a) data base acquisition, (b) maintenance impact analysis, (c) maintenance metrics model development, and (d) maintenance demand causal analysis. The findings represent the results of the research approaches and "lessons learned" during the implementation and completion of this research effort.

6.1 ASSUMPTIONS AND UNCERTAINTIES

Certain assumptions and uncertainties were inherent in the regression procedures used to detect the MIERs (section 3.2) and develop the maintenance metrics models (section 4.1).

1. The assembled data were accurate and unbiased.

2. Each data case value was a member of a continuous normal distribution of possible values for that data case (a necessary condition for least squares regression).

3. Each major independent variable appearing in each metrics model equation is unrelated to the other major independent variables in the model.

4. The range of values represented by the data samples used encompassed essentially the full range of possible Air Force-wide values for equipment, operational, and environmental characteristics for cargo/transports, bombers, and fighters.

5. The selections of the scalor ranges which were used to transform the qualitative variable data such as severity of vibration (refer to section 3.1.1) were

based on research and experience. As such were assumed to be valid quantitative measures of qualitative datum variables.

6. Many of the models, particularly in the cargo/transport and bomber categories are derived in part from data on older technology equipment. This may limit their predictive validity when applied to new, high technology systems unless they are used in conjunction with comparability analysis techniques which can bridge the gaps.

6.2 OVERALL FINDINGS AND RECOMMENDATIONS FROM THE PHASE III STUDY

The most important products of this study have, of course, been the developed maintenance metrics models, along with their underlying causal analyses. These metrics provide the necessary computational equations and supporting information to enable the user community to apply them immediately to aircraft equipment maintenance demand estimation problems. At this point, no further development is required on these metrics as applied to peacetime Air Force operations.

During the course of development of the metrics, certain important overall findings were revealed. As discussed in Section 4.3, the conventional usage factors (sortie rate, landings, and flying hours) proved to be of minor importance as measures of the maintenance demand of individual aircraft subsystems. In fact, an important lesson learned from the developed models was that there is usually not any one strong parameter that drives maintenance action demand. Instead, combinations of parameters from all three categories (equipment, operation, and environment) must be considered in order to develop the best maintenance metrics model for each individual aircraft subsystem. Certain classes of subsystems will be biased toward certain causal parameters, however. For instance, landing gear and flight surfaces seem to be influenced by usage. Engines are greatly influenced by operational considerations, such as throttle excursions (mission profiles) and environmental factors; e.g., corrosion problems. Modern avionics maintenance demand is generally more dependent on design complexity than on operational or environmental considerations. Also, it is important to note that there are important differences in the causal parameters comprising the maintenance metrics of cargo/transports, bombers, and fighters.

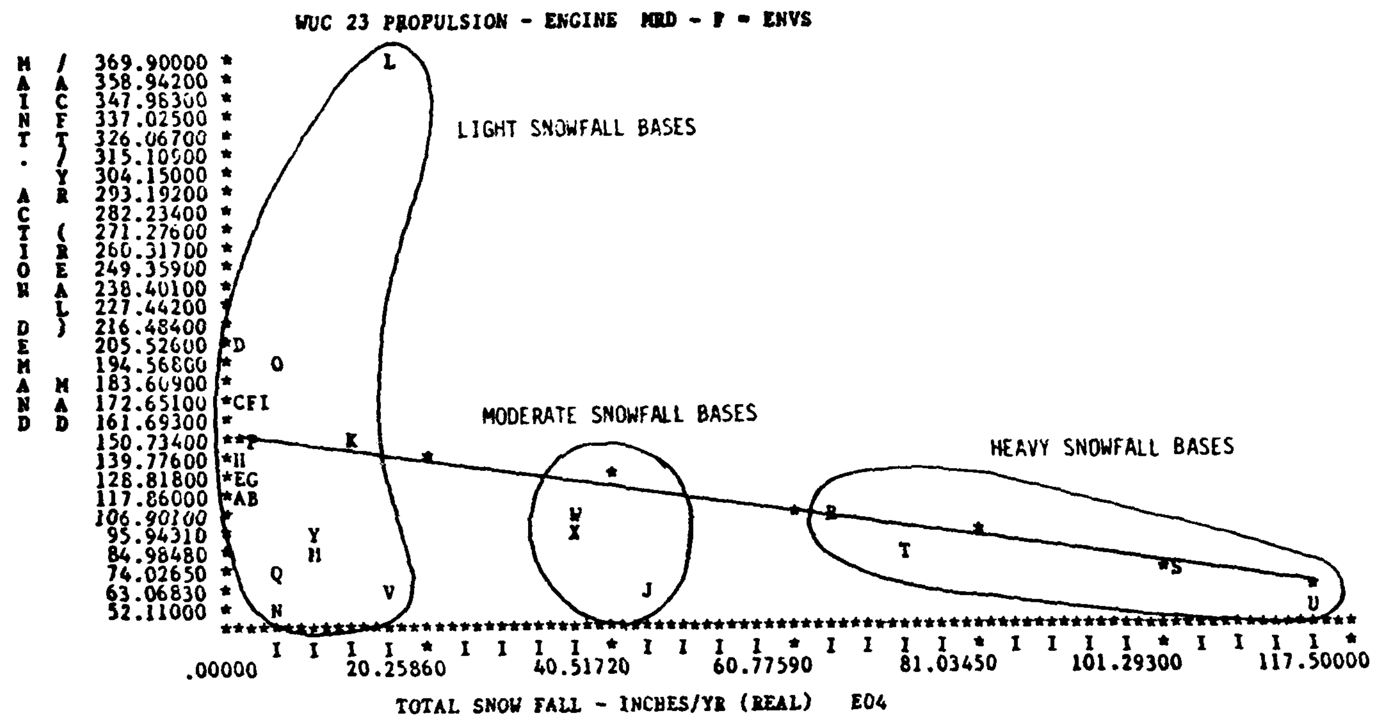
These differences are due largely to the differing design/performance, operational, and environmental regimes which apply to each category of aircraft.

The analysis of the causal factors underlying the developed metrics also turned up some important general findings. The base surveys discovered large amounts of unrecorded (in the standard Air Force data systems) ground operating time. This ground operating time would have biased the results of the maintenance metrics development effort if it had not been captured and included in the models. Spares shortages and long lead times are a chronic problem in the field and definitely affect maintenance efficiency and cannibalization. Base maintenance manning is adequate as to numbers, but there is a definite shortage in the skilled middle grades (specialist 5-level). There are adequate numbers of low-skilled 3-levels and management-type 7- and 9-levels. This void definitely affects maintenance efficiency.

Climate and weather were found to have a definite impact on aircraft subsystems maintenance demands. Although these impact factors were not generally as strong in statistical significance as some design and operational factors, they definitely were present in the data. The mean temperature of the study bases was generally positively related to maintenance demand under peacetime operating conditions. Interestingly, under peacetime operations, adverse weather had a negative effect on maintenance demand. That is, the worse the weather, the less the equipment required maintenance. It is posited that this phenomenon may be due to less flying, hence less failure during adverse weather. It is also possible that bad weather hampers maintenance to the point that the maintenance action rate is slowed. In other words less maintenance gets done and recorded per day.

Another climatic impact that showed strongly in the data was corrosion problems. This statistic appeared as expected with high and/or dry bases experiencing few problems and warm/wet/sea air bases having serious problems.

The climate and weather impacts of the typical environmental parameters, (total snowfall, mean minimum temperature, and aircraft corrosion problems) are illustrated in Figures 14, 15, and 16.

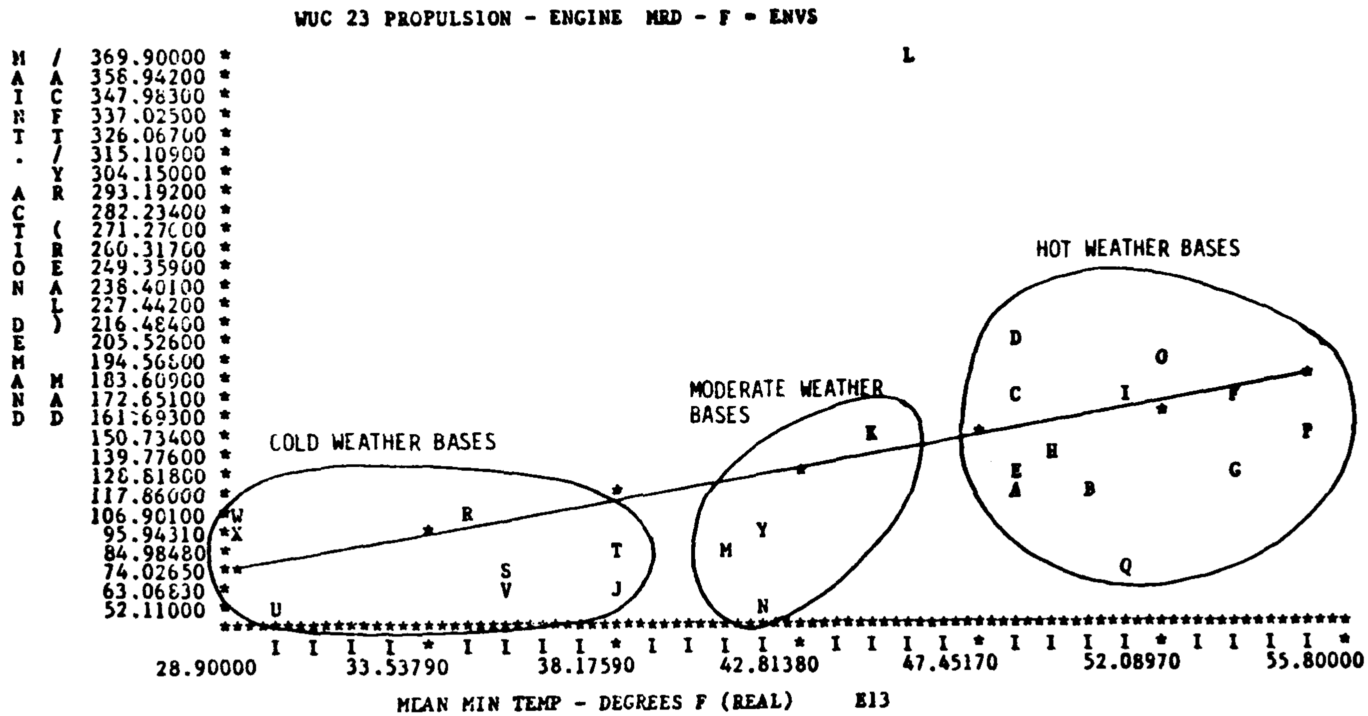


YD(ESTIMATE) = M*XI + B

CORREL.COEFF.(R) = -.39966
SLOPE (M) = -.80367
Y INTERCEPT (B) = 150.51700

A MARCKC-135A
B NORT C-141A
C TRAV C-141A
D TRAVIS C-5A
E MATHKC-135A
F KOB KC-135A
G CHAR C-141A
H POPE C-130E
I S-J KC-135A
J FAIRKC-135A
K MCGU C-141A
L DOVER C-5A
M RH-H C-130E
N MILD C-130E
O DYESKC-135A
P CARSKC-135A
Q L-R C-130E
R PLATKC-135A
S GRIFKC-135A
T PEASKC-135A
U LOR KC-135A
V ELLSKC-135A
W MIN KC-135A
X G-F KC-135A
Y MCORDC-141A

FIGURE 14 EXAMPLE OF COLD ADVERSE WEATHER EFFECTS ON PEACETIME MAINTENANCE DEMAND

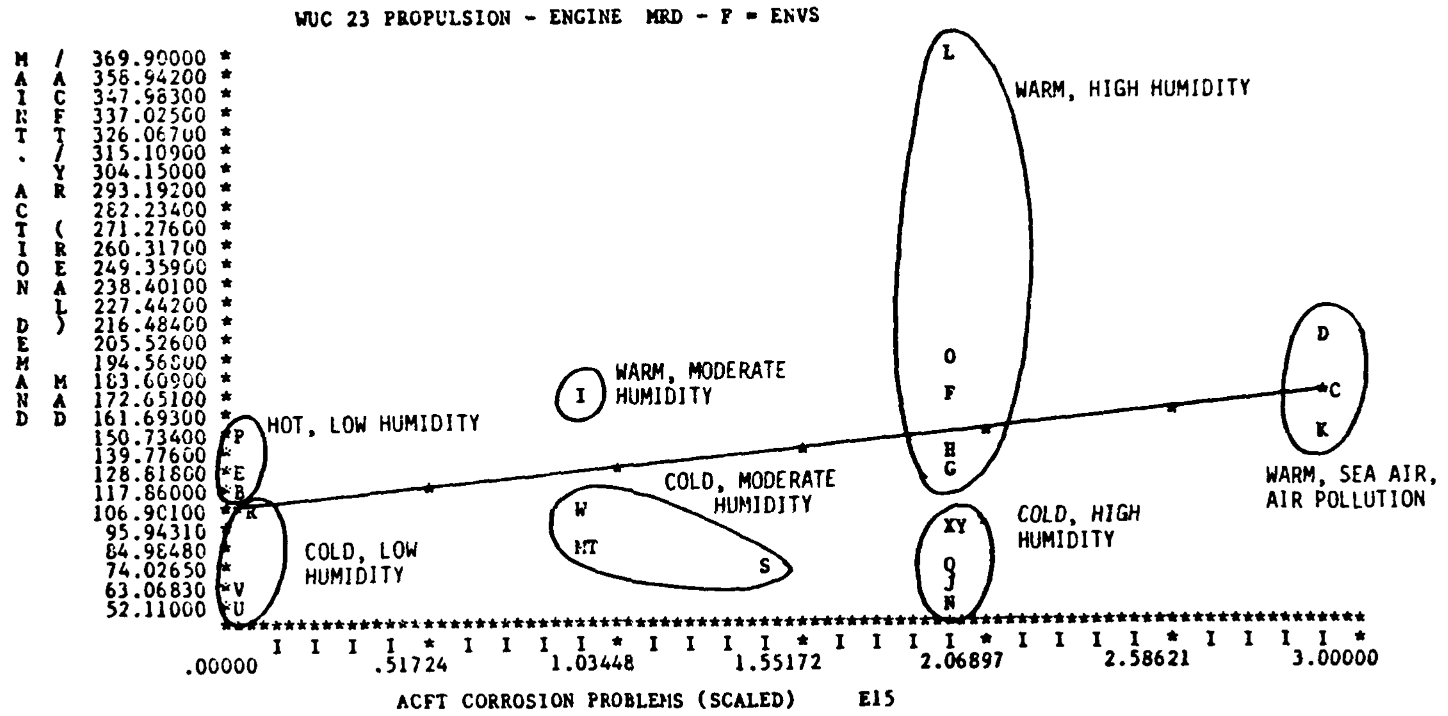


YD(ESTIMATE) = M*XI + B

CORREL.COEFF.(R) = .46417
SLOPE (M) = 3.80591
Y INTERCEPT (B) = -37.02730

A	MARCKC-135A	K	MCCU C-141A	U	LOR KC-135A
B	NORT C-141A	L	DOVER C-5A	V	ELLSKC-135A
C	TRAV C-141A	M	KH-H C-130E	W	MIN KC-135A
D	TRAVIS C-5A	N	HILD C-130E	X	G-F KC-135A
E	MATHKC-135A	O	DYESKC-135A	Y	MCORDC-141A
F	ROB KC-135A	P	CARSKC-135A		
G	CHAR C-141A	Q	L-R C-130E		
H	POPE C-130E	R	PLATKC-135A		
I	S-J KC-135A	S	GRIFKC-135A		
J	FAIRKC-135A	T	PEASKC-135A		

FIGURE 15 EXAMPLE OF CLIMATIC TEMPERATURE EFFECTS ON PEACETIME MAINTENANCE DEMAND



YD(ESTIMATE) = M*XI + B

CORREL.COEFF. (R) = .33858
SLOPE (M) = 23.09260
Y INTERCEPT (B) = 98.71350

A	MARCKC-135A	K	MCGU C-141A	U	LOR KC-135A
B	LOLT C-141A	L	DOVER C-5A	V	ELLSKC-135A
C	TRAV C-141A	M	RH-H C-130E	W	MIN KC-135A
D	TRAVIS C-5A	N	HILD C-130E	X	G-F KC-135A
E	MATHKC-135A	O	DYESKC-135A	Y	MCORDC-141A
F	ROB KC-135A	P	CARSKC-135A		
G	CHAR C-141A	Q	L-R C-130E		
H	POPE C-130E	R	PLATKC-135A		
I	S-J KC-135A	S	GRIFKC-135A		
J	FAIRKC-135A	T	PEASKC-135A		

FIGURE 16 EXAMPLE OF CORROSIVE ENVIRONMENT EFFECTS ON PEACETIME MAINTENANCE DEMAND

In conclusion, the most important end products of this study are new maintenance metrics that can increase the accuracy with which the maintenance demand rates of the various aircraft subsystems are predicted. These improved measures can now be used by the Air Force user community in their prediction and estimation efforts for.

1. Manpower determination studies.

2. Cost-of-ownership studies.

3. New basing and deployment planning.

4. Design trade studies for future aircraft.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AB	Air Base
ACFT	Aircraft
AFB	Air Force Base
AFE	Air Force Europe
AFHRL	Air Force Human Resources Laboratory
AFMEA	Air Force Management Engineering Agency
AFTO	Air Force Technical Order
AGE	Aerospace Ground Equipment
AMS	Avionics Maintenance Squadron
AVG	Average
BIT	Built In Test
BMW	Bomb Wing
CU	Cubic
EAC	Experience Analysis Center
EMAD	Estimate of Maintenance Action Demand
ENVIRON	Environment
EQUIP	Equipment
F-CLOCK	Failure Clock
FOD	Foreign Objects Damage
FT	Foot
FTW	Fighter Training Wing
HF	High Frequency
HR	Hour
IFF	Identification Fried or Foe
I/O	Input/Output
LBS	Pounds
LCOM	Logistics Composite Model
MAC	Military Airlift Command
MAD	Maintenance Action Demand
MAINT	Maintenance
MAW	Military Airlift Wing
MDC	Maintenance Data Collection
MH	Manhour
MIER	Maintenance Impact Estimating Relationship
MIN	Minute
MMH	Maintenance Manhour
MMM	Maintenance Manpower Model
MO	Month
MRD	Maintenance Resource Demand
NO	Number
NORM	Not Operationally Ready Maintenance
NORS	Not Operationally Ready Supply
NRTS	Not Repairable This Station

OCALC	Oklahoma City Air Logistics Center
OPNL	Operational
OR	Operationally Ready
ORG	Organization
O&S	Operations and Support
SAALC	San Antonio Air Logistics Center
SAC	Strategic Air Command
SPSS	Statistical Package for the Social Sciences
SRU	Shop Replaceable Unit
TAC	Tactical Air Command
TACAN	Tactical Air Navigation
TFW	Tactical Fighter Wing
TO	Technical Order
TR	Technical Report
TTW	Tactical Training Wing
UHF	Ultra High Frequency
USAFE	United States Air Forces in Europe
WUC	Work Unit Code
WT	Weight