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A COMPARISON OF AIRCRAFT
MAINTENANCE ORGANIZATIONAL
STRUCTURES

THESIS

Wesley C. Davis, Captain, USAF
Sanford Walker, Captain, USAF

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A COMPARISON OF AIRCRAFT
MAINTENANCE ORGANIZATIONAL STRUCTURES

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Logistics Management

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September 1992

Approved for public release; distribution unlimited

Preface

This study would not have been possible without the contribution of many people and organizations. We would specifically like to thank the personnel at HQ TAC/LGMP and the Naval Sea Logistics Center for providing the data used in this research. Two persons deserve special thanks, Squadron Leader McIntyre, RAF, and Maj Dempster, Canadian Forces. These two individuals spent their valuable time discussing their service's organization with us. In addition, we would like to thank members of the United States Coast Guard Auxiliary and K&G for their help.

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Wesley C. Davis
Sanford Walker

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Abstract

This study compares the aircraft maintenance structure being implemented by General Merrill A. McPeak with that of the previous structure typified by TACR 66-5. Historical aircraft data is used to compare organizational structures. Data from the USAF and USN is used to build regression models to determine if organizational structure contributes to combat capability. Statistical tests are used to determine if a significant difference exists between the two organizational structures.

Regression analysis and comparison of the results lead the researchers to conclude that a significant difference exists in the performance measures of COMO and Objective Wing organizations. While many reasons may account for this difference, the structure of the organization is a key determinant of performance.

A COMPARISON OF AIRCRAFT MAINTENANCE ORGANIZATIONAL STRUCTURES

I. Introduction

Background

The United States Department of Defense is reducing the size of its forces in response to the dissolution of the Soviet Union and to Congressional concerns over economic conditions. Despite this reduction, the mission of the United States Air Force (USAF) will continue to be to maintain combat ready forces prepared to support national policy objectives through military action (7).

The Chief of Staff of the Air Force, General Merrill A. McPeak, has outlined broad changes for the USAF and the aircraft and munitions maintenance (hereafter called maintenance) organizational structure (35:12, 28). The maintenance structure is changing drastically. Organizational and intermediate levels of maintenance are being split between the Operations and Logistics Groups respectively. Generically known as flightline and backshop maintenance, they have existed under a single chain of command for the last 35 years (18:126). Instituting this dual channel of authority is intended to provide, among

other things, equal or greater levels of effectiveness with reduced manpower (35:12, 28).

Before the recent reorganization of the USAF, tactical aircraft maintenance units were organized under the provisions of Multiple Command Regulation (MCR) 66-5. This directive placed all unit level maintenance under the functional authority of a single manager, the Deputy Commander for Maintenance (DCM). Organizational maintenance was performed by personnel assigned to Aircraft Maintenance Units (AMUs) that were attached to the fighter squadrons. These AMUs were not under the command of the fighter squadron commander (8).

Intermediate level maintenance fell under the responsibility of two maintenance squadrons. The Component Repair Squadron (CRS) was responsible for maintenance of individual parts removed from the aircraft such as avionics boxes, engines, and hydraulic actuators. The Equipment Maintenance Squadron (EMS) provided the capability to perform heavy maintenance such as phase inspections and was responsible for maintenance of the Aerospace Ground Equipment (AGE) and all activities in the Munitions Storage Area (MSA) (8:111-172).

The reorganization of the USAF will change this structure. No longer is there a single functional manager for the maintenance complex. All organizational level, and some intermediate level, maintenance personnel are now assigned directly to the individual fighter squadrons. The

remnants of the intermediate level capabilities will transfer to the new Equipment Maintenance Squadron under the command and control of the new Logistics Group Commander. This new structure is referred to in this study as the Objective Wing.

This revamped system is very similar to the organization of the United States Navy's (USN) Naval Aviation maintenance units deployed at sea. Gen Merrill A. McPeak compared his proposed Composite Wing, using the Objective Wing structure, to the Navy's carrier wing.

The best example of a composite wing is provided by the modern aircraft carrier, where the typical deck loading creates a true composite with a range of capabilities tailored to the mission. (25:9)

Krisinger also compares the Navy's air wing to the new composite wings. The composite wings will share the organizational structure of the new Objective Wing (21:32-40). In the carrier air wing, all organizational level maintenance is performed by specialists assigned directly to the fighter squadron under the command and control of the fighter squadron commander. The remaining intermediate level maintenance is consolidated under one functional manager, the Aircraft Intermediate Maintenance Officer (AIMO). The intermediate functions are split among the General Maintenance, Avionics/Armament and the Support Equipment Maintenance Divisions.

The combined aircraft and munitions maintenance career fields make up 28% of the Air Force (30:38-57). Because

this group is the single largest group of personnel in the Air Force, reorganizing to reduce its size can provide significant benefits.

General Issues

The USAF maintenance structure is changing. However, there are no published studies which predict or analyze the effects of this change as measured by a performance value such as mission capability (MC) rate. Previous changes in maintenance organizational structure were either the direct result of studies undertaken to improve a specific measure such as the number of sorties flown per day, or arose from the requirements of combat.

Problem Statement

There has been no comparison made to determine if organizational structure contributes to, or detracts from, an aircraft maintenance unit's performance measures.

Research Questions

1. Can a model (either mathematical or analytical) be developed which can accurately predict an organization's performance as reflected in the MC rate?
2. What variables contribute to the prediction of this maintenance performance?

3. Are the variables in models of the USAF and USN organization's performance the same?
4. Do statistically significant differences exist between the levels of performance achieved by USAF and USN aircraft maintenance organizations as predicted by mathematical or analytical models?

Scope

This study will compare the performance of the old USAF maintenance structure with an organization similar to the new structure. The organization which best represents the new structure is the USN, specifically USN fighter squadrons deployed at sea. The researchers will determine if a statistically significant difference exists between the performance of maintenance organizations of the USAF and USN. One measure of this performance is in the MC rate of assigned aircraft.

The aircraft studied will be limited to USAF F-15 and F-16 and to USN F-14 and F/A-18.

Overview

This thesis is organized with five chapters. Chapter I is the general introduction to the situation being examined by the researchers. It contains the background, problem statement, research questions and scope of the research. Chapter II contains a review of literature found on subjects

related to the problem and summarizes some techniques relevant to the analysis. Chapter III describes the methodology used in performing the comparison of the target organizations. Chapter IV begins the examination of the results from the treatments outlined in the methodology. Chapter V will present conclusions reached from the comparison and recommendations for future studies.

II. Literature Review

Introduction

Congress has recently passed a military budget bill which sets the tone for Air Force operations for the next five years. This bill takes the manpower levels now in force and mandates a 25% reduction (35:12,28).

Aircraft maintenance is one of the primary areas of concern with the impending drawdown. The Air Force Specialty Codes (AFSC) which make up aircraft and munitions maintenance represent the largest career groups in the Air Force at 28% of the total enlisted force (29:51). If that pool of manpower is reduced by a fourth, it will have a noticeable effect upon the ability of the Air Force to defend the nation.

Scope

This chapter will examine the history of maintenance in the USAF and the way in which the USAF and the USN organize their aircraft maintenance structure. Other countries organizations are included for comparison. The two countries examined are the United Kingdom and Canada. In addition, the new organizational structure of the USAF will be examined. Three previous master's theses using modelling techniques to predict aircraft availability will be

examined. The researchers will include a general discussion on mathematical modelling techniques used to determine the effects of independent variables on predictors and the techniques used to validate these models. Standard techniques used to determine the level of significance between the results of two models will be discussed. In addition, current literature on comparing different organizations in similar industries will be reviewed.

History of Aircraft Maintenance in the USAF

In the USAF, changes to the aircraft maintenance organizational structure have traditionally been undertaken in response to problems as they arose. As a result, overall revision of the entire system has been a long term, piecemeal process. (20:39)

1909 - 1945. Prior to the first world war aircraft were technologically unsophisticated. Enlisted personnel, who were experts on the entire aircraft, performed all repairs. This was the beginning of the crew chief, an individual who was responsible for all servicing and repair of the aircraft. During the first world war rapid growth of the Aviation Section forced a structure onto the maintenance organization. A brief outline of the structure is listed below.

First echelon - Maintenance was performed by the aircrew; e.g., servicing the aircraft, performing pre-flights and daily inspections, making minor adjustments and repairs.

Second echelon - Maintenance was usually performed by the ground crew of operating units, air base squadrons, and aircraft detachments; e.g., servicing aircraft and equipment, performing periodic preventive maintenance inspections, making minor adjustments and repairs.

Third echelon - Maintenance was performed by specialized mechanics from base shops and sub-depots; e.g., removal and replacement of major unit assemblies and all minor repairs to aircraft structures and equipment.

Fourth echelon - Maintenance was performed by highly specialized mechanics in air depots; e.g., major repairs, modifications, and overhauls. These depots were located at Dallas, Texas; Montgomery Alabama; and Indianapolis, Indiana. (18:30)

This structure was required because of the rapid build up of Army Aviation and the resulting need for more maintenance personnel. It was easier and faster to train personnel to perform one specific duty, or group of related duties, than to train personnel to perform all repairs.

In the years between the two world wars, Army aviation began to swing from specialized mechanics back to the generalization of the pre-World War I era. "The mechanic was again being trained to maintain his entire aircraft" (18:41). This was a return to the crew chief system first instituted in 1913 and was brought about by reductions in the size of the Army Air Corps and its manning.

With the entry of the United States into the Second World War, aircraft maintenance once again underwent change. In the continental United States (CONUS), Headquarters Army Air Forces instructions outlining the maintenance organizational structure were mandatory. Overseas theater commanders were allowed to modify or even ignore these

instructions. The organizational structure of overseas units was varied and adapted to the local situation. In contrast, CONUS units were structured and uniform. During this time the use of specialties began to become prevalent within CONUS. The organization of base maintenance units consisted of Flying Line Maintenance and Production Line Maintenance. In 1945 the Army formalized this structure in its United States Army Strategic Air Force Regulation 65-1.

1945 - 1957. The period from 1945 to 1957 was a period of demobilization and change. The U.S. Air Force became a separate service in 1947, the Berlin Airlift was the new Air Force's first challenge in 1948 and Korea exploded in 1950. The main points of interest to this study occurred between 1947 and 1949.

The end of World War Two created many problems for the new Air Force. For example, rapid demobilization led to manpower shortages with many of the highly skilled mechanics leaving the military for more lucrative jobs in industry. The shortage of skilled technicians along with the lower manning in general, left personnel who were unable to maintain the complex aircraft in use at that time. To counter this loss of skilled personnel and to improve the quality of maintenance, the Air Force instituted the Hobson Plan in 1947 (18:74).

This plan made the wing headquarters the highest echelon on a base. Subordinate to the wing headquarters were four groups: the combat group, the maintenance and supply group, the airdrome group, and the medical group. Combat squadrons within the combat

group had the responsibility for the first and second echelon maintenance on assigned aircraft. This included engine changes. The maintenance squadron within the maintenance and supply group was responsible for third echelon maintenance and all maintenance on base flight and transient aircraft. (3:26)

Following the Hobson Plan, the Air Force conducted a survey in 1948 to gather information from the field on maintenance practices. As a result of this survey, a report by Maintenance Division outlined a plan to

increase the effectiveness of the peacetime maintenance organization; reduce maintenance costs; and finally, provide a sound basic organization for mobilization expansion. (37:141)

The underlying concept of this plan used concepts taken from industry, primarily the production line. Personnel were trained to high skill levels on one specific task. The main advantage of this system was the technicians were trained to the necessary skill level in a short time. Strategic Air Command (SAC) took the lead with this concept and established technician specialization as their maintenance concept. This concept was published as SAC Regulation 66-12 in 1949. The purpose of this regulation was:

to establish a functional aircraft maintenance organization within the wing-base organization which would insure full utilization of personnel and facilities to produce maximum availability of aircraft. (36:141)

Tactical Air Command (TAC) did not adopt a mandatory regulation for maintenance organization, as did SAC. TAC left the organization of maintenance up to the unit commander, much like overseas practice in the Second World

War. The next major event in aircraft maintenance took place in 1957 with TAC's adoption of a new maintenance concept.

1957 - 1972. The Air Force underwent many changes in the period from 1957 to 1972. The year 1957 saw a fundamental shift in TAC's aircraft maintenance organization. In this year control of the maintenance personnel and the aircraft changed from the operational squadron commander to a Chief of Maintenance (34:1). The next important event for aircraft maintenance took place in 1972 with project RIVET RALLY.

All major commands began to use AFM 66-1 in 1957, first pioneered by SAC as SACR 66-12. This change was driven by the complexity of the new jet aircraft coming into the inventory. These new aircraft were more complex than older aircraft and were not designed for ease of maintenance. AFM 66-1 continued the move towards more and more centralization of the maintenance complex. Crew chiefs were the only personnel assigned to work on the flightline. All other maintenance personnel were assigned to backshop functions. These personnel were located off the flightline and had to be dispatched to assist the crew chief as required. Dispatching specialists required communication and coordination. Communication and coordination required staff personnel. Staff personnel required paperwork and documentation. The result was high numbers of overhead

personnel who were not directly involved in sortie production on the flightline (18:127).

Another problem with centralized maintenance as outlined in AFM 66-1 was the unit did not train as it would fight. Tactical wings in the early sixties were very large, some with hundreds of fighter aircraft. In addition, these wings were tasked to provide small numbers of fighters for routine deployments to overseas locations. When a group of fighters deployed, the maintenance personnel and aircraft were assembled as a unit for the first time. Unit integrity and unit pride were lacking (24). The Air Force went to war in Vietnam with this structure but began to realize it was not capable of producing a high number of sorties.

1972 - Present. The Air Force carried centralization of the maintenance complex through Vietnam. In 1972, feeling the pressure of budget cutbacks, the Air Force created project RIVET RALLY. RIVET RALLY "was designed to centralize base level maintenance organizations, standardize functions within those organizations, and develop a common maintenance management directive for use by all commands" (34:17-29). This process standardized all maintenance throughout all commands in the Air Force.

The end of fighting in Vietnam led to a large scale reduction of the United States' military forces. The focus of military attention shifted to the defense of Western Europe and peace in the Middle East. The Air Force attempted to meet its commitments by maintaining high

readiness. However, high readiness required many training sorties, and many training sorties required maintenance to perform more work. Once again, a shrinking military was asked to perform more with less (18:142-143). There was a rising concern in the Air Force that maintenance could not produce the number of sorties required.

In the past, there had been a shortfall in aircraft sortie production to meet the needs of operational and aircrew training requirements. An identified cause for the inability to meet those requirements was maintenance capability and training. (3:76)

In an attempt to find a solution to generating more sorties, the Chief of Staff, USAF, created the Maintenance Posture Improvement Program (MPIP). MPIP's charter directed it to "develop new ways to perform required maintenance with diminishing numbers of personnel without compromising safety standards" (3:76). MPIP created a board that was tasked to consider manpower utilization, training of maintenance personnel, modernization of Aerospace Ground Equipment, and the organizational structure of maintenance (3:77). One of the board's findings was the belief that a war in Central Europe would require very high sortie rates for the first 10-15 days. The board asked the question "can maintenance generate a sufficient number of sorties and sustain it over a period of time?" (3:77). Their answer was no.

The 1973 Arab-Israeli War (Yom Kippur) occurred at approximately the same time as the MPIP board concluded the Air Force would need to produce very high sortie rates each day in the next war. The Israelis flew extremely high

sortie rates, as the MPIP board had predicted. To find out how the Israelis accomplished this high sortie production, TAC sent a team to Israel to study their maintenance organizations. The team found the Israelis assigned the personnel who were directly responsible for repairing, servicing, and launching aircraft to the flightline. Personnel who did not directly contribute to generating aircraft were assigned to shops off the flightline. The team felt the Israelis' system of maintenance "appeared to have great possibilities in the fighter environment" where "rapid aircraft turnaround, sortie generation and surge capability were essential" (3:78). HQ USAF urged TAC to adopt this organizational model in 1974.

The findings of the MPIP board and the study of Israeli maintenance practices lead to the introduction of the Production Oriented Maintenance Organization (POMO). POMO took advantage of the natural on- and off-equipment split in maintenance (3:80). Flightline personnel directly supported the sortie generation of aircraft. Specialist dispatching was abolished. Personnel who were not involved in sortie generation were assigned to backshops to repair the black boxes removed on the flightline. The maintenance personnel on the flightline were assigned to Aircraft Maintenance Units (AMUs) and cross trained to perform many general types of simple tasks.

POMO did not produce the numbers of sorties expected. When General W. L. Creech took command of TAC in 1978 he

instituted a study to determine what TAC's capability was. The study found sortie production fell 7.8% from 1969 to 1978. The major reason for the decline in sortie production was not due to external factors such as reduced funding. It was simply maintenance's inability to produce the required number of sorties programmed. (18:19-20). General W. L. Creech felt the organization of maintenance was the major contributing factor to this decline.

TAC created the Combat Oriented Maintenance Organization (COMO) to fix this problem. COMO was formalized as Multiple Command Regulation (MCR) 66-5, the title later changed to Tactical Air Command Regulation (TACR) 66-5. The Combat Oriented Maintenance Organization differed from POMO in the following manner:

1. Each squadron/AMU performed its own scheduling and was responsible for its own utilization rate.
2. Each squadron/AMU had its own dedicated analyst to provide statistical analysis.
3. Wing score-keeping functions such as Maintenance Supply Liaison were eliminated and supply responsibility was decentralized to the squadron/AMU.
4. Each squadron/AMU had its own supply support section.
5. Each squadron/AMU performed its own debriefing after a mission.
6. The squadron/AMU had its own pool of Aerospace Ground Equipment.
7. Dedicated crew chiefs were assigned to each aircraft.
8. Each squadron/AMU dispatched its own flightline personnel to jobs.

9. There was squadron/AMU integrity; red hat maintenance personnel worked on red tailed jets flown by red scarfed pilots. (18:25)

Unit pride, which was the central theme of COMO, was the result (18:149-150). However, implementation of COMO was very manpower intensive.

The results of the transition to COMO have been dramatic. Sortie production, from the third quarter of 1978 through the third quarter 1983, rose at an annual rate of 11.2 %. In the first full year under COMO, 1979, TAC flew all of its programmed sorties for the first time in a decade. (18:150)

Maintenance Organizational Structure

Several alternative methods of organizing aircraft maintenance are commonly used in different air forces around the world. The researchers will examine several of these air forces through journal articles and reports as well as through their own regulations and directives. This literature search will serve to establish a baseline for comparison with both the TACR 66-5 structure and the new Objective Wing structure. The service of most interest to this study is that of the United States Navy because it will be used as a comparison to the new Objective Wing structure in this study.

United States Air Force, TACR 66-5. Prior to 1992, the standard CONUS based tactical USAF unit was organized under a single Deputy Commander for Maintenance (DCM) as outlined in TACR 66-5. This pre-1992 organization is the focus of the current study. Subsequent mention of the organizational

structure of CONUS based USAF tactical units will refer to the pre-1992 organization. The DCM worked directly for the Wing Commander and was responsible for all base level aircraft maintenance. Underneath the DCM were three maintenance squadrons: Aircraft Generation Squadron (AGS), Component Repair Squadron (CRS), Equipment Maintenance Squadron (EMS) (8). See Figure 1.

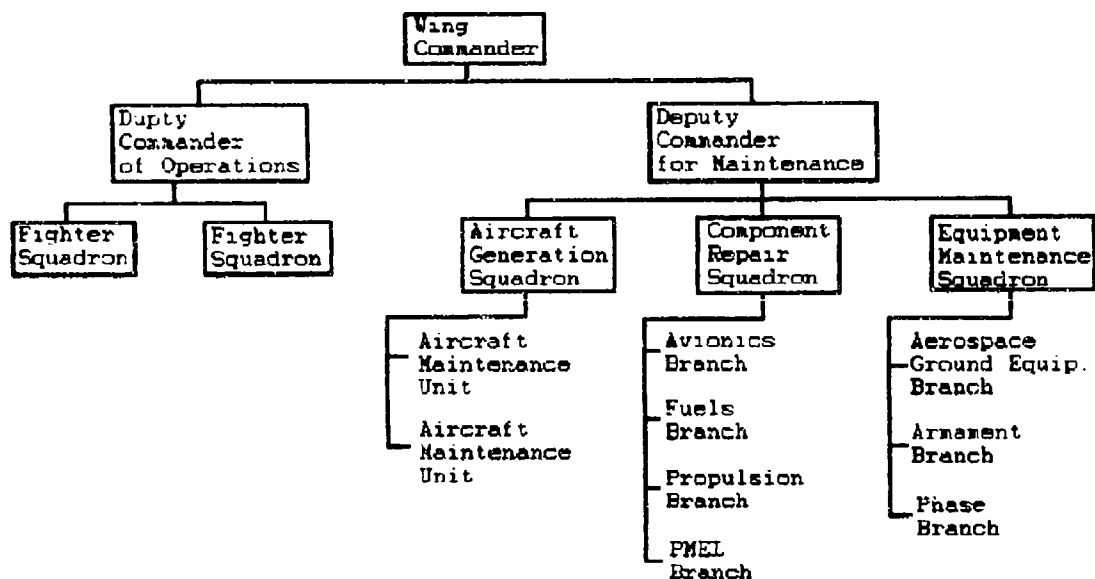


Figure 1. USAF Aircraft Maintenance Organizational Structure, TACR 66-5 (8)

Each of the three squadrons had specific areas of responsibility. AGS was responsible for launching, recovering, and servicing aircraft, and was arranged into Aircraft Maintenance Units (AMUs). The AMUs were responsible for their own scheduling, utilization rate and maintenance analysis. AMUs were partnered with a flying

squadron and only performed maintenance on their own aircraft. The AMU concept allowed dedicated maintenance personnel to work closely with the flying squadron to enhance mission capabilities.

The typical AMU contained two crew chief flights (usually called APG Flights), a Specialist Flight, a Weapons Flight and a Support Section. See Figure 2.

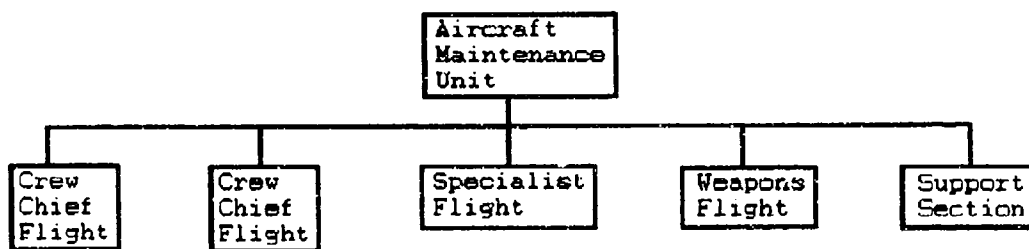


Figure 2. USAF Aircraft Maintenance Unit Organization (8)

The crew chiefs in the APG Flights performed servicing, inspection and maintenance on the aircraft they were assigned. The Specialist Flight contained the avionics technicians, hydraulic technicians, electricians, environmental specialist and power plant mechanics. The Weapons Flight personnel were responsible for loading munitions and maintenance of the aircraft weapons release

systems. The Support Section maintained tools, test equipment and technical orders (TOs). A small staff assisted the AMU supervisor in managing the AMU. The staff included the functions of Plans and Scheduling, Administration, Training and Dispatch/Debrief (8:72-111)

CRS was responsible for off-equipment maintenance on avionics components and fuel systems. It was composed of four branches: Avionics Branch, Fuels Branch, Propulsion Branch, and Precision Measurement Equipment Laboratory Branch (PMEL). With the exception of Fuels Branch, personnel from CRS were not routinely dispatched to the flightline.

EMS was responsible for off-equipment maintenance on munitions, Aerospace Ground Equipment (AGE), phase inspections, and fabrication. EMS was authorized four branches: Munitions Branch, AGE Branch, Maintenance Branch, and Fabrication Branch (8).

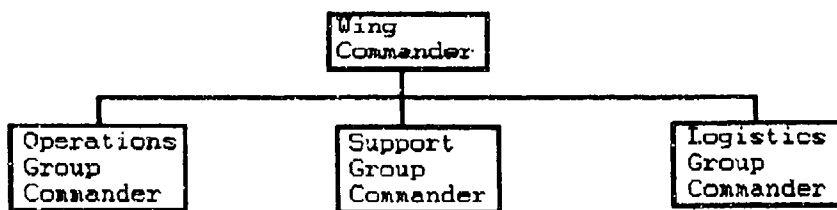


Figure 3. USAF Maintenance Organization, Objective Wing (12)

United States Air Force, Objective Wing. The Objective Wing as described by General Merrill A. McPeak, will be: "one base, one wing, one commander". It is intended that air force wings should train as they will fight. It will accomplish this by having a single wing commander at each base with flight crews and flightline maintenance personnel working for the flying squadron commander. The backshop maintenance personnel will work for a logistics group commander. This is the same basic wing structure used in Operation Desert Storm (10:99). See Figure 3.

The aircraft maintenance structure will be organized to place the on-aircraft maintenance functions under the Operations Group commander. The supply, transportation, and off-aircraft maintenance functions will be under the command of a single person in the Logistics Group.

This structure places the sortie producers under the flying squadron commander and the support shops under the Logistics Group commander. An accountability matrix will ensure a system of checks and balances.
(12)

The Operations Group Commander will report directly to the Wing Commander. Underneath the commander there will be operations squadrons (flying squadrons) and an Operations Support Squadron. The on-equipment maintenance officer will report to the operations squadron commander.

The maintenance officer will have an APG Flight, Weapons Flight, Specialist Flight and Support Flight. The functions of these flights are the same as those under the TACR 66-5 structure. See Figure 4.

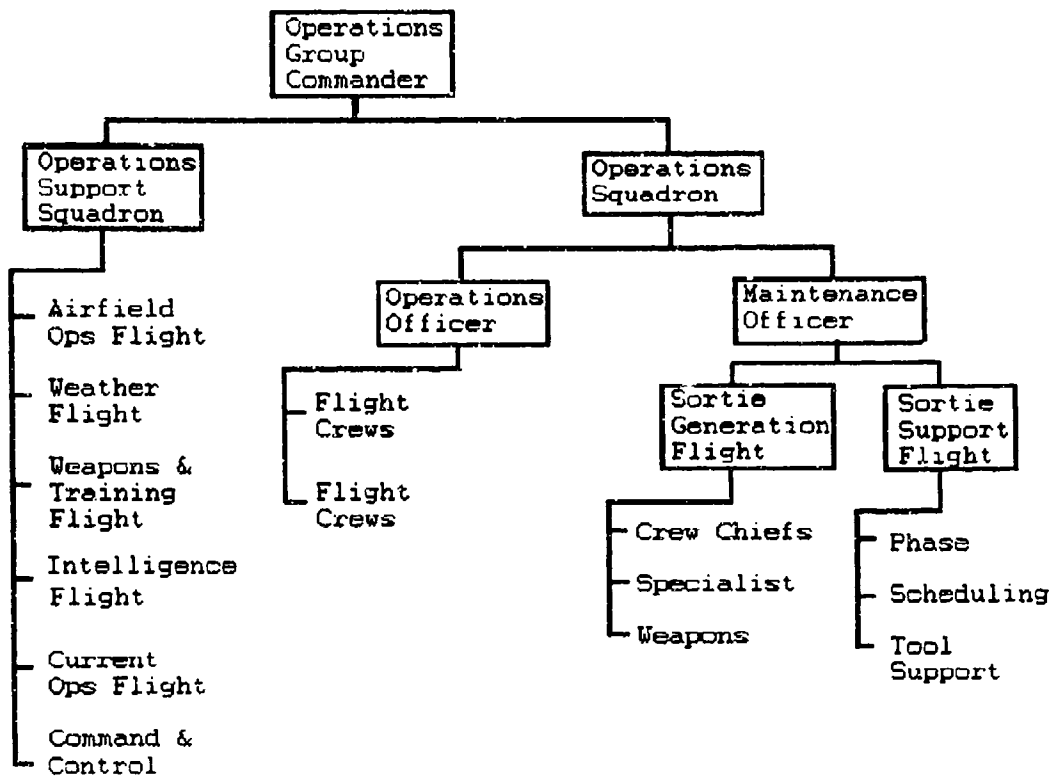


Figure 4. USAF Maintenance Organization, Operations Group (12)

The Logistics Group Commander will absorb the supply squadron, logistics plans division, the former CRS and EMS and the transportation squadron. The former CRS and EMS will be consolidated into a Maintenance Squadron responsible for off-equipment work. See Figure 5.

United States Navy. The United States Naval Aviation Maintenance Program (NAMP) delineates its organization into several types: ship-board, shore-based, large readiness and training squadrons, Marine Corps Aviation units, and detachments with four or less aircraft (5). For the purpose of this study only ship-board units will be discussed.

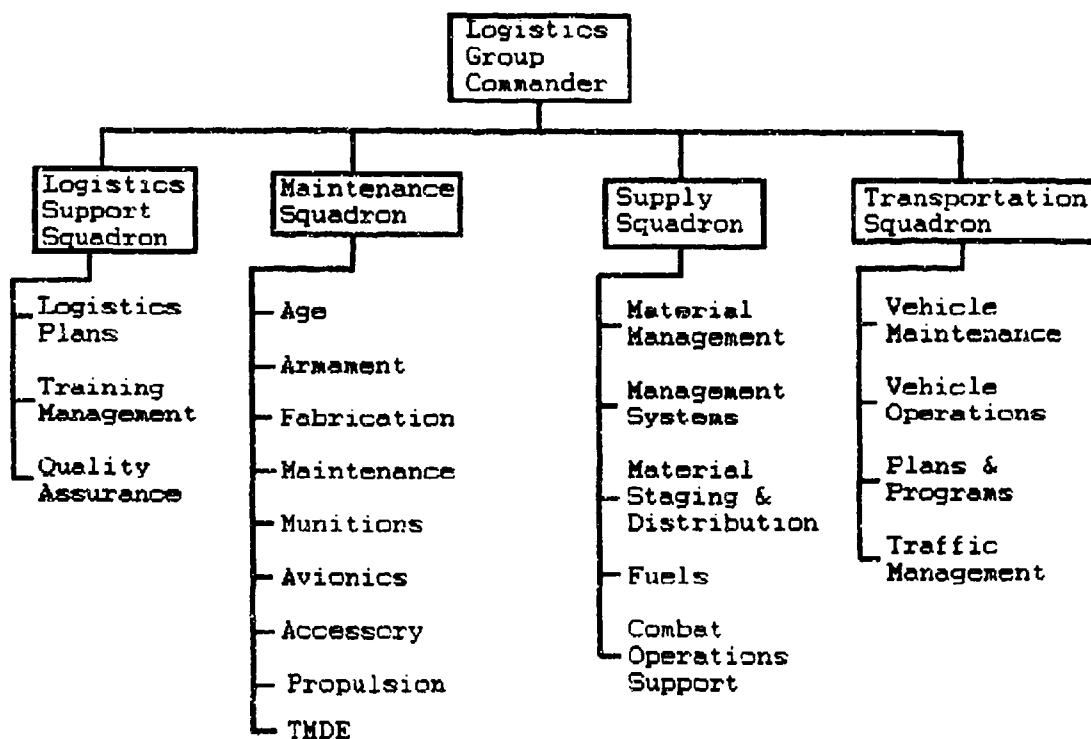


Figure 5. USAF Maintenance Organization, Logistics Group (12)

The ship-board aircraft maintenance structure of the United States Navy closely resembles the structure of the new USAF Objective wing. There is a single commander over both operations and intermediate level maintenance. The operations function owns the organizational level maintenance. The intermediate level maintenance is the responsibility of a separate commander (15). This is a loose analogy as the Navy's ship's commanding officer has some operational responsibilities in addition to his intermediate level maintenance responsibilities. For example he is responsible for the command and control functions, the responsibility of the Operations Group

commander in the Air Force. The top level organization of ship-board maintenance units is shown in Figure 6.

On board ship, aircraft maintenance is separated into Organizational level and Intermediate level.

The Navy assigns all organizational level maintenance activities to a single Maintenance Officer with an assistant. The Maintenance Officer reports directly to the fighter squadron commander, who has direct command authority of all organizational level aircraft maintenance. Figure 7 shows the USN's organizational level maintenance structure.

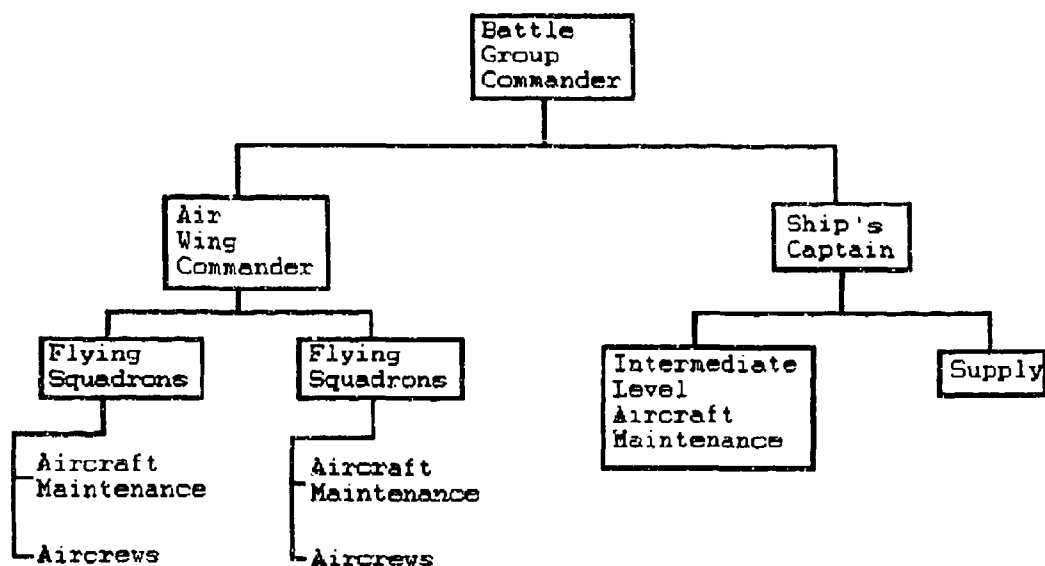


Figure 6. USN Maintenance Organization, Top Level. (15)

This officer is either a career maintenance officer or an officer on flight status. Either the Maintenance Officer or his assistant must be a career maintenance officer with specific training qualifications outlined in OPNAVINST 4790.2E, Volume II.

Underneath the maintenance officer there are three branches: Quality Assurance/Analysis, Maintenance/Material Control Officer, and Maintenance Administration. The branch of interest to this study is the Maintenance/Material Control Officer.

The Maintenance/Material Control Officer has six divisions under him: Maintenance Control, Material Control, Target Division, Aircraft Division, Avionics/Armament Division, and Line Division.

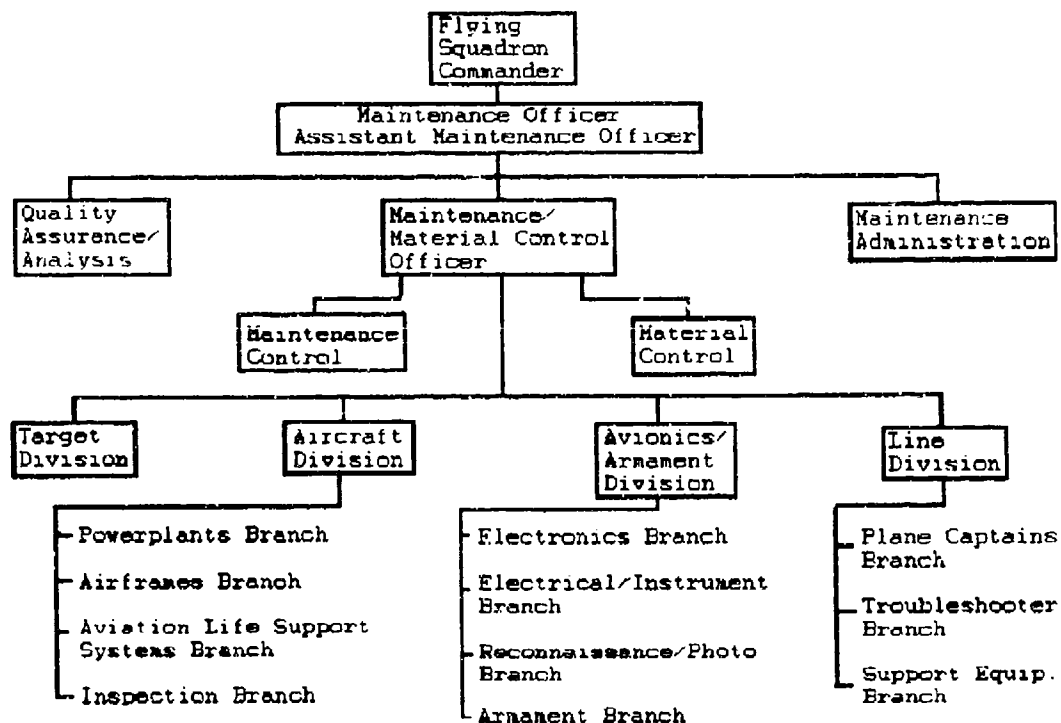


Figure 7. USN Maintenance Organization
O-Level (5:3-3)

Division, and Line Division. The Target Division is not considered in this study as there is no direct USAF counterpart.

Only three divisions have personnel who work on the flightline: Aircraft Division, Avionics/Armament Division,

and Line Division. The functions under the Aircraft Division are Powerplants Branch, Airframes Branch, Aviation Life Support Systems Branch, and Inspection Branch. The Avionics/Armament Division contains the Electronics Branch, Electrical/Instrument Branch, Reconnaissance/Photo Branch, and the Armament Branch. The specialists in both the Aircraft Division and the Avionics/Armament Division are dispatched to the flightline to support the Line Division. This is analogous to the Specialist Flight and Armament Flight in a USAF AMU. The third division directly supporting the flightline is the Line Division. This division contains the Plane Captains Branch, Troubleshooters Branch, and the Support Equipment Branch. This division is similar to the Aircraft Generation Squadron in the USAF with the exception of the Support Equipment Branch which would be placed in a backshop. In this structure the maintenance officer has control over all of the organizational aircraft maintenance personnel assigned to the fighter squadron.

All intermediate level maintenance at sea is organized under the functional command of the Aircraft Intermediate Maintenance Officer (AIMO). The qualifications for the AIMO and the assistant parallel those for their organizational level equivalents. All intermediate level aircraft maintenance is the responsibility of the ship's commanding officer. The AIMO heads the Aircraft Intermediate Maintenance Department (AIMD) which splits into three major production branches (6). See Figure 8.

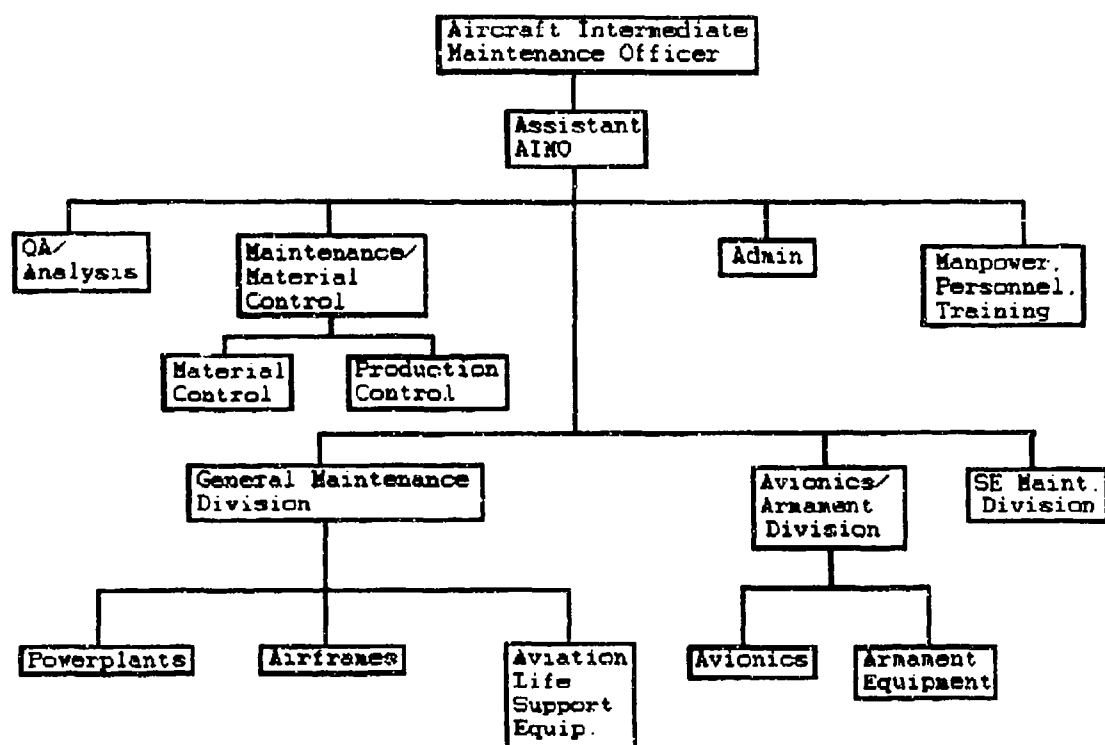


Figure 8. USN Maintenance Organization,
I-Level (6)

The General Maintenance Division is split into sections responsible for off-equipment power plant maintenance, airframe maintenance and aviation life support equipment. The Avionics/Armament Division performs off-equipment work on avionic and armament components in the two separate branches. The final division is the Support Equipment Maintenance Division. This section performs all work on the Navy's equivalent of aerospace ground equipment.

The AIMO has a staff to assist in management of the AIMD. The Maintenance/Material Control section is

identical in function to its counterpart in the fighter squadron.

Additional staff functions are the traditional sections of Quality Assurance/Analysis, Administration and Manpower, Personnel and Training.

Canadian Forces, Air Command. Canadian forces arrange their maintenance personnel in a different manner. The senior maintenance officer, the Base Aircraft Maintenance Engineering Officer (BAMEO), is responsible for all aircraft maintenance activities, see Figure 9 (4:3).

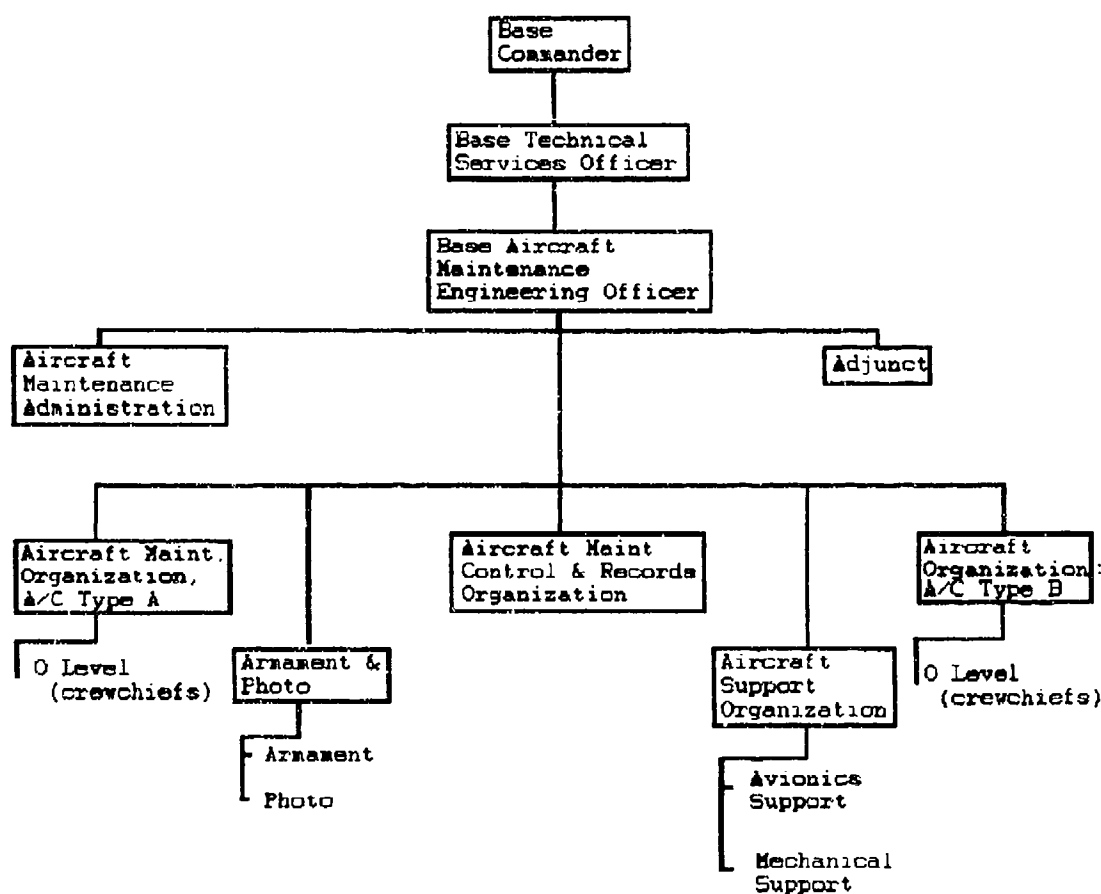


Figure 9. Canadian Forces, Air Command, Maintenance Organization (4:3)

Under the BAMEO, flightline units are established based on the type of aircraft they support. They perform all organizational level maintenance. One example is the Aircraft Maintenance Organization-Tracker, which supports Tracker maritime reconnaissance aircraft. At Canadian Forces Base-Summerside, two separate operational squadrons fly the Tracker aircraft. One maintenance organization supports both squadrons (4:3-E1). Different units are set up to maintain different aircraft at the same base. At CFB Summerside, Buffalo and Voyageur search and rescue aircraft are maintained by the Aircraft Maintenance Organization Search and Rescue (4:3-F1).

Intermediate level maintenance is accomplished by the Aircraft Maintenance Support Organization (AMSO) and the Armament and Photo Organization (4:3-G1, 3-18). These two organizations perform all off-equipment repair (regardless of aircraft type) much as the intermediate maintenance squadrons in the USAF.

The aircraft maintenance organizational structure closely resembles the structure of the USAF under TACR 66-5.

Royal Air Force. Another basic organizational structure has evolved within the Royal Air Force (RAF), United Kingdom. The Royal Air Force aircraft maintenance organizational structure resembles that of the USAF Objective Wing, see Figure 10.

Much like the USAF Objective wing and the US Navy, organizational level maintenance is performed by personnel

assigned to the flying squadron they support. These maintenance personnel are under the command of the flying squadron commander.

The intermediate level of maintenance belongs to a separate functional commander. Overall intermediate level maintenance is the responsibility of the BAMEO, the commander of the Engineering Wing. The Engineering Wing performs the common intermediate functions of propulsion, structural repair and avionics, all off-equipment work (23). A copy of the RAF's maintenance directive, AP100A-01, was requested from the RAF but was not supplied.

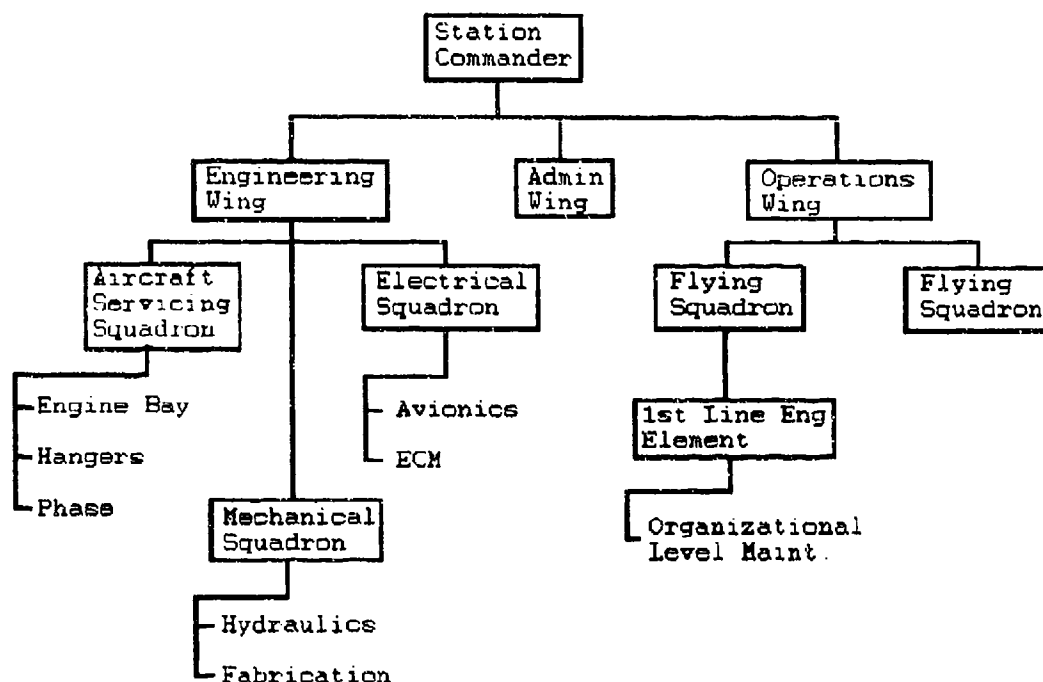


Figure 10. Royal Air Force Maintenance Organization (23)

The RAF aircraft maintenance structure is parallel to the USAF Objective Wing. The flying squadron commander has

command authority over all organizational level maintenance personnel. A separate commander has command authority over all intermediate level maintenance activities.

Previous Research

Previous research into the effect of maintenance variables on mission capability was examined, both for completeness and for applicability to the problem stated by the researchers. Each of these theses examined the relationship between maintenance variables and their effect upon some dependent measure of performance or productivity.

Gililland. Gililland studied productivity in the USAF. He specifically identified the productivity measures used and attempted to "understand the relationships among the various productivity measures" (14:4). His research evaluated how [aircraft] maintenance productivity measurements affected the USAF productivity objectives.

One of Gililland's research questions directly applicable to the current study is "Of the measures implemented by aircraft maintenance organizations, which contributes most significantly to explaining maintenance productivity?" (14:5). To answer this question, Gililland used six months of aircraft maintenance performance data from the Military Airlift Command (MAC). Gililland used the software package, System for Elementary Statistical Analysis (SAS) with six months of data to build regression models to

determine the variables with the most significant contribution to various dependent variables. From this analysis, the independent variables found to contribute the most to the MC rate were cannibalization rate, awaiting maintenance and awaiting parts discrepancies and average possessed aircraft (14:105).

Gililland's study is of interest because it examined the relationships of several variables on MC rate and it validated MC rate as one of the most important indicators of a unit's effectiveness. In addition, the SAS software package was used to build regression models using these variables.

Jung. Jung examined the existing performance measures of several SAC aircraft. His research attempted to find the "maintenance production constraints that limit or enhance production capability", the "relationships between the maintenance constraints and an organization's production capability" and "what maintenance constraints can be used in a predictive model of a maintenance organization's sortie production capability" (19:3).

The research aim of Jung's study is different than that of the present study. Jung attempted to use existing maintenance indicators to predict a unit's capability. His study is only of interest because of his methodology; he used regression techniques using historical data. Twenty seven months of data were obtained from SAC HQ. Twenty one months of data were used to build the models and the

remaining six months of data used to validate them. The six months chosen for validation were consecutive months; no attempt was made to randomize the data withheld for validation.

Gonnerman. In her thesis, Gonnerman took a significantly different approach to analyzing performance factors. This study used a technique known as Constrained Facet Analysis and evaluated its applicability to maintenance indicators (16:1). The study took data from 5 months of activity at a specific Air Force base operating A-10 aircraft (16:2). The research target was split into two categories, the Aircraft Maintenance Unit and the aircraft itself (16:16). Using selected input and output variables and reciprocals, Gonnerman graded the efficiency of the AMUs and 28 different aircraft (16:25,28).

The Constrained Facet Analysis (CFA) performed for this thesis involved the use of special computer programs not available at AFIT (16:29). Additionally, the conclusion reached by the author did not show an clear advantage to using this type of analysis (16:56). In fact, Gonnerman listed several disadvantages to CFA, among them the complexity of the method and the need for training for those using it (16:56). For these two reasons, more traditional methods of statistic analysis were selected for this thesis.

The one important factor in this analysis lies with the selection of the input and output measures. As in other studies, the mission capable rates of an aircraft were

chosen as output variables (19:22). Additionally, two important measures were established as input variables: manhours per flying hour (per time period) and the number of sorties scheduled and flown (19:19,20). While some variables were chosen for analyzing the AMU and others affected the individual aircraft analysis, both were used in evaluating performance of the maintenance organization in general. Many of these same variables will have an affect on the researchers' study using regression analysis.

Inter-Service Comparisons. There is a complete lack of written material on a comparison between the USAF and other air forces' maintenance organization. This was a surprising discovery. The researchers expected to find numerous comparisons based on the frequent examination of the organizational structure of the USAF. Some examples of these examinations are Projects RIVET RALLY and RIVET WORKFORCE and the Maintenance Posture Improvement Program.

Inter-Industry Comparisons. Literature concerning analytical comparisons between companies within a like industry were reviewed to gain insight into methods used by other researchers. The works of a well-known author in this field was searched for analytical methodologies on intra-industry comparisons.

Vogel has studied the differences between selected Japanese industries and the corresponding American industry. In the two texts reviewed, analytical methodology was not discussed. Instead of analytically comparing industries in

the two countries, Vogel discusses broad cultural differences, the effects of the Second World War on both economies and the drive on the part of the Japanese to become world leaders in selected industries (32; 33).

A search of periodicals was conducted to determine if other authors have made analytical intra-industry comparisons. This search revealed numerous studies by economists evaluating several factors in intra-industry comparisons.

One article is of interest because of the method the researchers used in selecting companies within an industry to compare to each other. They chose companies based on such factors as common language, average per capita income and average trade orientation. The factors chosen are common factors used by economists to describe an industry. The same rationale was used by the authors of this study to choose the service of comparison and the aircraft to compare against. Another point of interest in the same article is their use of regression analysis to determine the amount of similarity among like industries. However, no mention is made of the method used to validate the models (1).

Another article, also by an economist, used ten years of historical data to build regression models to determine the similarities among companies within an industry. Again, this article is of interest to the present study because of its use of regression analysis and historical data to determine similarity (2).

Modelling Techniques

The underlying premise of this thesis is that several known variables contribute significantly to the measure of performance known as MC rate. After these variables are identified for both the USAF and the USN, historical data will be used to predict the MC rate of USAF and USN fighter aircraft. Following this step, the data from the USAF will be used in the model developed for the USN to determine if the USAF could produce better MC rates using the Navy's maintenance concepts. A method is required that will establish which variables contribute the most to this prediction.

Emory and Cooper provide a discussion on the selection of an appropriate multivariate technique based on whether the research question is stated in terms of dependency or interdependency. If there are criterion and predictor variables in the research question, then the research question is stated in terms of dependency. When dependency exists, three techniques may be employed to test to determine the relationship between the dependent and independent variables. These techniques are Multiple Analysis of Variance (MANOVA), discriminant analysis and multiple regression (13:628).

MANOVA is used to determine "the relationship between two or more dependent variables and classificatory variables or factors" (13:636).

Discriminate analysis is used to classify data into two or more groups. This method is not applicable for predicting results based on past data and so will not be explored further.

Multiple regression is a method used to determine relationships between variables. Many standard textbooks outline the techniques and limitations of regression analysis.

Often there exists a functional relationship which is too complicated to grasp or to describe in simple terms. In this case we may wish to approximate to this functional relationship by some simple mathematical function, such as a polynomial, which contains the appropriate variables and which graduates or approximates to the true function over some limited ranges of the variables involved. By examining such a graduating function we may be able to learn more about the underlying true relationship and to appreciate the separate and joint effects produced by changes in certain important variables. (11:2)

Regression analysis allows the researcher to construct a mathematical model to determine which independent variables contribute the most to predicting the dependent, that is the predictor, variable. "One way to decide quantitatively how well a straight line fits a set of data is to note the extent to which the data points deviate from the line" (22:460). The method used is to determine the deviation, or errors, from the line to the actual data points. The sum of these errors equal zero but the square of the sum of errors (SSE) will be equal to something other than zero. If all possible lines with their SSE are

calculated, one line will be found with a minimum SSE. This line is the line with the best fit of the data points.

The general form of the regression model is

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \dots + \hat{\beta}_k x_k + \epsilon$$

$\hat{y}$ = predicted dependent variable

$\hat{\beta}_0$ = predicted y-intercept

$\hat{\beta}_i$ = predicted coefficients of independent variable

x_i = independent variable

ϵ = random error (22:522)

Given there are variables that can be modeled mathematically to predict a specific y , the question then becomes, how is the best regression equation selected? Draper and Smith discuss various methods for selecting the best regression equation, three of which are presented below (11:294).

1) All possible regressions. This method involves fitting every combination of equations using all possible variables. Draper and Smith caution that this method can produce a model with more variables than is necessary (11:302).

2) Backward elimination. In this method each possible variable is entered into the regression equation and tested to a predetermined level of significance. If the variable does not meet the predetermined level of significance, it is removed from the equation. This procedure is repeated until

all variables have been tested. Draper and Smith state that this method is satisfactory (11:307).

3) Stepwise regression. This method begins by adding or subtracting variables in the regression equation one at a time and testing their level of significance for predicting the y-value. Draper and Smith's opinion is that stepwise regression is one of the best methods for selecting variables and recommend its use (11:310).

Model Validation

Regression will take any values provided and attempt to fit a line to those values. The question then becomes, is the model useful for predicting the dependent variable?. One way to check the validity of a model is to leave out some of the data set, build the model using the remaining data and then attempt to predict the dependent variable using the remaining independent variables. A variation on this method is to split the data set in half and then use the remaining half to validate the model. (11:420)

Both of these validation methods require that part of the data set be withheld from the data used to build the model. This reduces the amount of data available for building the model and thus reduces its accuracy. One method available that overcomes this shortcoming was suggested by C. I. Mosier in 1951 (27:10-11). Mosier suggests splitting the data set in half, building a model

with each data set then validating each model with the other half of the data set. If there is no significant difference between the results from the validation it can be assumed each model is an accurate predictor of the system being modeled. After validation, the data set is then recombined and a third model built using all of the data. This approach allows the model builder to use all available data for the actual model building process and thus the resulting model will be more accurate than one built using only part of the data. (27:165)

Several researchers have used this method since Mosier first proposed it; none report any problems using it. Gross et. al. used double cross-validation in their work on predicting flexion and peak torque in the human knee (17).

Van der Meer employed Mosier's method in his study of the interaction of the abundance of marine life in intertidal waters and the environment. He reports that the use of double cross-validation brings precision to the parameter estimates. (31)

Thorndike describes double cross-validation in detail as a method of enhancing the size of a data set during regression model building (30:165).

After an initial model is developed, the overall effectiveness of the model and the amount of contribution each variable has on the overall model must be determined. Several steps are required before a model can be called a good model.

1) The overall model must be tested for goodness-of-fit.

2) The ability to accurately predict the dependent variable must be established.

There are several generally accepted methods for testing for goodness-of-fit in a regression model. Each independent variable in the final model can be tested for the level of contribution by examining related t-statistics. The F-statistic is used to evaluate the usefulness of the overall model. The amount of variability the independent variables account for in the model is expressed by the r-squared value. The term, r-squared, is also called the multiple correlation coefficient. The r-squared will measure what proportion of the variation from the mean $\bar{y}$ is explained by the regression model (11:33). A final means of evaluating the goodness-of-fit in a regression model is to analyze a plot of residuals to determine if there are any non-linear terms in the independent variables.

Chapter Summary

A review of literature was made in four areas: 1) a general history of the maintenance structure of the United States Air Force 2) different air force maintenance structures, 3) previous research and 4) modelling techniques.

The U.S. Air Force has undergone many changes in aircraft maintenance organizational structure since the beginning of its history. The TACR 66-5 structure was a direct result of the Maintenance Posture Improvement Program. These requirements were validated by the Yom Kippur war of 1973. Tactical Air Command was sufficiently impressed with the Israelis' performance in that war to modify their own structure to emulate that of the Israelis'. Finally, the past cannot be forgotten. George Santayana has stated:

Progress, far from consisting of change, depends on retentiveness... Those who cannot remember the past are condemned to fulfil it. (28:414).

Air Forces of different nations have structures with varying degrees of difference from our own. Some are very similar to our own, such as the Canadians, and some use a structure that splits the maintenance personnel between an operations manager and a logistics manager.

There are many methods of modelling a system, one method used by other researchers is multiple regression. Multiple regression uses independent variables to predict a dependent variable. The amount of contribution the independent variables make to the prediction is expressed by the r-squared value, the remaining information in the model is random error or unknown variables.

After an exhaustive search, no literature could be found on any study comparing the organizational structure of one air force's maintenance organization to another.

However, several studies were found that used regression analysis to predict an aircraft maintenance unit's effectiveness or productivity.

III. Methodology

Introduction

This chapter outlines the statistical techniques used to answer the research questions presented in Chapter I. Subsequently, these results will be applied to answer the problem statement.

One of the primary research objectives is to identify the independent variables which will allow an accurate prediction of the dependent variable, the Mission Capable (MC) Rate. The independent variables will be a subset of the key maintenance indicators tracked by senior Air Force and Navy managers to monitor and grade the performance of maintenance organizations.

Data Sources

The data analyzed in this comparison were obtained from official sources within the Department of Defense and are unclassified. Headquarters, Tactical Air Command (HQ TAC/LGMP) provided historical data on assigned aircraft as well as the number of personnel authorizations for each mission design series (MDS) of aircraft: F-4E, F-4G, F/EF-111A/D/G, F-15, F-16, F-117 and A/OA-10. The historical maintenance indicators covered a 24 month period from October 1989 through September 1991.

The Naval Sea Logistics Center provided the equivalent maintenance indicators for the F-14, F/A-18, A-6 and A-7 types of aircraft. The period covered by the data is from July 1989 through June 1991. Additional data on USN aircraft maintenance personnel authorizations came from the Naval Manpower Analysis Center (NAVMAC).

Two assumptions concerning the data have been made by the researchers. First, the data represents the true status of the affected MDS; i.e., no data has been falsified by the organizations responsible for the data. Secondly, any errors inherent in the data collection and recording systems are equal across all sources. For example, errors which normally occur collecting F-16 data are equivalent to those errors occurring in the F/A-18 system, effectively negating their effects on the statistical analysis. This however does not concern human errors which may be found in data collection and documentation. The researchers feel these human errors and differences can neither be identified nor compensated for.

The data sets received from each source have been subjected to a three part process to determine their applicability to the study. First, only two MDSs from each service will be examined. From the USAF, the F-15 and F-16 aircraft from operational wings will be used. The targets of analysis from the USN will be the F-14 and F/A-18 deployed at sea. Each of these MDSs represents the typical airframe currently in service. Additionally, a close

similarity in mission and technology exists between the F-15 and F-14 as well as between the F-16 and F/A-18. This characteristic will facilitate the comparisons between the services and reduce any errors caused by dissimilar aircraft types.

The purpose of this study is to test the performance difference based on structure; therefore each supplied statistical variable will be judged as to whether or not it is a function of structure as shown in Table 1.

TABLE 1
KEY MAINTENANCE INDICATORS

<u>USAF</u>	<u>USN</u>	<u>Abbreviation</u>	<u>Structure</u>	<u>Duplicate</u>
Mission Capable	Mission Capable	MC	No	No
Not Mission Capable	Not Mission Capable	NMC	No	No
Total Not Mission Capable Maintenance	Total Not Mission Capable Maintenance	NMCM	No	Yes
Total Not Mission Capable Supply	Total Not Mission Capable Supply	NMCS	No	No
Total Not Mission Capable Both	Total Not Mission Capable Both	NMCB	No	Yes
Abort Rate	Aborts	ABRT	No	No
Aircraft Sortie Utilization Rate	Flight Utilization per Aircraft	SUTE	No	No
Aircraft Hourly Utilization Rate	Flight Hours	HUTE	No	No
Authorized Personnel per Aircraft	Maintenance Personnel per Aircraft	SPA	Yes	No
Maintenance Manhours per Flying Hour	Direct Maintenance Manhours per Flying Hour	MPH	Yes	No

The variables which represent structural influences will be eliminated from further selection processes. The influence demonstrated by a variable representing structure may be included in the error term associated with the statistical analysis of the data sets. The remaining variables may account for any organizational differences unrelated to structure.

Much of the data given to the researchers was duplicative and as such will not be included in the modelling process. For example, a regression model of:

$$\text{MC rate} = 1.00 - 1(\text{NMCM}) - 1(\text{NMCS})$$

could result from a stepwise regression analysis using all supplied factors. This model is not useful because it fails to include the factors of manpower availability, aircraft utilization functions and the intensity of labor required to keep the aircraft flying. It simply subtracts known values from a constant. The example model would theoretically have a r-squared value of 1.00. To account for this duplicity in statistical bookkeeping, each variable has been evaluated as to whether or not it represents unique data or data also represented in other variables (see Table 1).

Previous studies have attempted to model the aircraft maintenance system using as many as 32 independent variables (19). As reported in Chapter II, the results of these studies were mixed and inconclusive. The researchers feel a more parsimonious model will yield results different from earlier studies.

Analytical Tools

The SAS System for Elementary Statistical Analysis, Version 6.06 installed on the Air Force Institute of Technology's VAX cluster system will perform the regression analysis. The spreadsheet program Quattro Pro, Version 4.0 installed on a PC will be used for all other calculations. A sample SAS program is shown in Appendix B.

Correlation Analysis

Selection of the final variables for the model will be made using correlation analysis. Using the coefficient of correlation for each variable, as measured against the dependent variable MC rate, the relative value of the relationship of each independent variable will be examined. This step will identify those variables which explain the behavior of the dependent variable.

It can be argued whether the final variables are the sole determinants of the MC rate of a MDS. However, other studies have performed similar analysis on virtually all available variables and have failed to agree on the results. The combined 30 years of experience of the researchers will permit them to analyze the effects of the determinants used for this study. Considering the results of earlier studies and this combined experience, the researchers' technique of developing a more parsimonious model may prove to be more accurate and reliable.

Regression Analysis

From each data set obtained, 24 cases will be fitted to a probabilistic model using stepwise regression performed by the SAS System. Stepwise regression will be used to find the model which most closely predicts the dependent variable. The results of this treatment will yield one regression equation for each MDS of aircraft within each service.

Goodness-of-fit. Each model will be evaluated with a combination of the model's coefficient of determination (r-squared), the F-statistic and the p-value. Two other measures of goodness-of-fit are the t-value and an analysis of the residuals. These tests are commonly accepted measures for evaluating the usefulness of a regression model (30:540).

The r-squared of each equation is that fraction of variation in the model's independent variable which is attributable to the model itself (30:541). The r-squared statistic has a range of 0 to 1 with 1 representing a model whose entire variation is attributable to the model.

The second goodness-of-fit measure allows the model to be evaluated using various hypothesis. This F-statistic is "the ratio of the explained variability divided by the model degrees of freedom to the unexplained variability divided by the error degrees of freedom" (30:542). In practice, the value of the F-statistic indicates the degree to which the model accommodates the variability of the equation. The

greater the value of the F-statistic, the more accurately the equation predicts the dependent variable.

The p-value (shown on the SAS outputs as Prob > F) expresses the probability that the actual F-statistic is greater than the F-statistic calculated by the regression equation.

The contribution of each independent variable to the overall model is another important aspect of this study. The analysis performed by SAS includes a valuable tool to determine this contribution. A t-value is calculated for each independent variable and is placed against the hypothesis that the coefficient of the variable is zero. The higher the t-value, the greater the variable contributes to the model (30:529).

The residuals from the models, the difference between actual and predicted independent variables, will be plotted and analyzed for trends and patterns to verify satisfaction of the basic regression assumption of normality of residuals (30:527). Any trends observed in the residual plots will result in transformation techniques being used to return the dependent variable to an additive form for greatest regression accuracy (30:679).

Validation. Validation of the model will use a technique first developed in 1951 (27:165). Each data set will have cases numbered from 01 to 24 representing consecutive calendar months. The data sets will be divided by odd/even numbered months and the two sets will be used to

build separate regression models. Dividing odd and even months will tend to offset any seasonal fluctuations in the data and equally spread their affects across both models.

The separate models' goodness-of-fit will be evaluated as previously outlined. Each model will then be validated using the 12 months data from its sister model. This technique is called double cross-validation and allows the maximum number of points for building the overall experimental model (27:165). After each half-set model is cross validated, the data will be recombined to form a 24 case regression model.

Comparison Testing

Comparison tests will be made to determine if one organization performs at significantly higher levels than the other. One of the traditional indicators of an aircraft maintenance unit's performance is MC rate. In a regression equation, the factors that determine the predictor variable are the intercept, the independent variables and the error term. If the two models use the same independent variables, none of which influence structure, then the error term should contain all influences, including structure, not represented by the independent variables.

Two comparison tests will be performed on the results of the regression models.

First, paired t-tests will be performed on the difference between the predicted MC rates of the Air Force MDSs and the predicted MC rates of the USN MDSs. This test will determine if a significant difference exists between the two services as represented by the comparison MDSs.

Secondly, the independent variables from each aircraft type will be placed into the model of the comparison MDS. This will yield a predicted MC rate for each month of data for each comparison pair. The researchers will test each value of predicted MC rate against the actual rate using the paired difference t-test. The data pairs will be tested under the hypothesis:

$$H_0 : \text{MC rate}_{\text{usaf}} = \text{MC rate}_{\text{navy}}$$

$$H_A : \text{MC rate}_{\text{usaf}} \neq \text{MC rate}_{\text{navy}}$$

This examination is a parametric test designed specifically to compare paired groups. Results of this treatment will establish whether differences exist between the performance outputs of the USAF and USN.

Chapter Summary

Multiple regression is a powerful and dependable tool for developing models which can predict a value based on other factors. The multiple regression applications reviewed in this chapter will allow the researchers to answer the first three research questions. The parametric

testing of actual and predicted MC rates will allow
answering of the final research question.

IV. Findings and Analysis

Introduction

This chapter presents the results of the statistical analysis outlined in Chapter III. These results will be discussed in Chapter V. This discussion will attempt to answer the research questions presented in Chapter I. In addition to specific answers, the authors will present the conclusions they have drawn from the data. They will then attempt to generalize these conclusions to provide meaningful information concerning aircraft maintenance organization. This chapter follows the sequence of Chapter III. Tables summarizing the results of the analysis will be included for clarity as required. A discussion of the results will be included in each section.

Variable Selection

Characteristics of the key maintenance indicators were summarized in Chapter III, Table 1. Two characteristics of each indicator were examined.

1: Organizational structure. A determination was made whether or not each key maintenance indicator is a function of an organization's structure. The researchers found that the number of maintenance personnel per aircraft (SPA) was directly related

to the type of structure an organization developed. For example, the COMO organization used a large staff function which tended to raise the average number of personnel authorized to a wing based on the number of assigned aircraft. Conversely, a deployed Naval Aviation wing has a smaller staff function and subsequently a lower number of authorized personnel per assigned aircraft.

2: Duplication. The researchers also determined if the indicator was an alternative statistic used to track information collected by other indicators. The researchers found TNMCM and TMNCB duplicated information tracked by NMCS and NMC. The indicator NMC was not included in the data sets. NMC was shown to be a simple arithmetic difference from 1.00 as discussed in Chapter III.

Variables found to exhibit the characteristics listed above were deleted from further consideration.

The indicator MMH was deleted from the data sets based on discussions with HQ TAC. HQ TAC no longer uses MMH as an indicator of maintenance performance because of its unreliability. In addition, it is not directly related to manhours expended for sortie generation. This is caused by management pressure to account for at least eight hours of labor per person per workday (26). There are many

non-maintenance activities typically documented as maintenance labor. This causes an inflated MMH rate throughout all MDSs in the USAF.

The indicators chosen as independent variables for the statistical analysis were NMCS, SUTE, HUTE and ABRT. The dependent variable was MC.

Correlation Analysis

The SAS package calculated the correlation of each independent variable with respect to the dependent variable, MC. The results of this analysis are summarized in Table 2. For brevity, Table 2 lists each MDS with its independent variables as they correspond to MC rate. The full correlation table for each MDS is in Appendix D.

TABLE 2
CORRELATION COEFFICIENTS:
INDEPENDENT VARIABLES TO MC RATE
(BY MDS)

<u>MDS</u>	<u>NMCS</u> <u>(p-value)</u>	<u>HUTE</u> <u>(p-value)</u>	<u>SUTE</u> <u>(p-value)</u>	<u>ABRT</u> <u>(p-value)</u>
F-14	-0.90575 (0.0001)	-0.14234 (0.5070)	0.18275 (0.3927)	0.34586 (0.0978)
F-15	-0.37388 (0.0719)	-0.016706 (0.4352)	-0.11717 (0.5856)	-0.46222 (0.0230)
F-16	-0.93873 (0.0001)	-0.22965 (0.2804)	-0.48805 (0.0155)	-0.34902 (0.0946)
F/A-18	-0.94083 (0.0001)	0.41805 (0.0421)	0.36527 (0.0792)	-0.11630 (0.5884)

The p-value below each correlation coefficient is the probability that the coefficient is equal to zero. The associated p-values for each independent variable indicate the degree of significance of the correlation relationship. A correlation coefficient of 1.0 indicates a strong direct and a coefficient of -1.0 indicates a strong inverse relationship between the independent variable and the dependent variable. A correlation coefficient of zero indicates a lack of a relationship between the independent variable and the dependent variable.

The independent variable NMCS shows a strong negative correlation with all MDSs except the F-15. This indicates that as the NMCS rate increases, the MC rate decreases. Because NMCS is the percentage of time an aircraft is unavailable due to a lack of required parts, it follows NMCS will reduce the MC rate. All of the correlation coefficients are highly significant at the 0.0001 level with the exception of the F-15 with a p-value of 0.0719. This indicates NMCS has a strong relationship with MC rate for the F-14, F-16 and F/A-18. NMCS has a lesser relationship with the F-15 MC rate as indicated by its higher p-value and lower correlation coefficient.

The relationship of HUTE to MC is inconsistent among the four MDSs. The variable HUTE is negatively correlated within the F-14, F-15 and F-16 data sets. However, a positive correlation exists between HUTE and MC for the

F/A-18. Only the F/A-18 shows a significant correlation to the dependent variable with a p-value of 0.0421. The high p-values for the F-14 and F-15 indicate a strong probability that the true correlation coefficient is zero. The F-16 p-value indicates a lesser probability the true correlation coefficient is zero.

As in the case of the relationship of HUTE to MC, SUTE is also inconsistent among the four MDSs. The variable SUTE is negatively correlated within the F-15 and F-16 data sets. However, a positive correlation exists between SUTE and MC for the F-14 the F/A-18. This split is consistent among the services. USAF aircraft show a negative correlation while USN aircraft are positively correlated. The two oldest MDSs, the F-14 and the F-15 show a high p-value associated with their coefficients. This indicates a relatively high probability that their respective coefficients are zero. Conversely, the low p-values associated with the newer F-16 and F/A-18 indicate a low probability that their coefficients are zero.

The last independent variable, ABRT, again shows inconsistency among the MDSs. Unlike SUTE, there appears to be no consistency between services or aircraft age. The F-14 shows a positive correlation with the remaining MDSs all showing a negative correlation. The p-values for the F-14, F-15 and F-16 all indicate a fairly strong probability that the correlation is not zero. The high p-value for the

F/A-18 indicates a strong probability that a correlation between ABRT and MC is absent.

Regression Analysis

Stepwise regression was performed by SAS on the selected independent variables using all 24 cases. Table 3 shows the variables selected by SAS in the stepwise regression analysis.

TABLE 3
STEPWISE REGRESSION ANALYSIS
(BY MDS)

<u>MDS</u>	<u>NMCS</u>	<u>HUTE</u>	<u>SUTE</u>	<u>ABRT</u>
F-14	X		X	
F-15				X
F-16	X		X	
F/A-18	X			
(X indicates selection)				

The results of the stepwise regression selection process closely match the results of the correlation analysis. All stepwise models used NMCS except the F-15. The F-15 correlation of NMCS to MC had a relatively high p-value. The independent variables entered into the other three MDS stepwise models were inconsistent. The F-14 and F-16 models

both used NMCS and SUTE. The F-15 model only used ABRT while the F/A-18 only used NMCS.

The research questions center around comparing the performance results of the two different services based on similar aircraft. The inconsistency of independent variables selected by stepwise regression does not allow direct comparison of different aircraft types. Direct comparison requires that the models being compared use the same variables.

Using all four independent variables in the regression model would provide the most valuable comparison between different aircraft. The four independent variables account for the major measures of effect on MC rate. The choice of four independent variables is supported by the researchers' professional knowledge and experience.

TABLE 4
REGRESSION ANALYSIS SUMMARY
(BY MDS)

<u>MDS</u>	<u>INTERCEPT</u> <u>(t-value)</u>	<u>NMCS</u> <u>(t-value)</u>	<u>HUTE</u> <u>(t-value)</u>	<u>SUTE</u> <u>(t-value)</u>	<u>ABRT</u> <u>(t-value)</u>
F-14	82.898637 13.098	-1.772915 -8.660	-0.135422 -0.970	0.703684 1.7710	-0.838504 -1.316
F-15	92.706294 24.535	-0.344407 -1.073	0.003704 0.120	-0.09359 -0.613	-0.946179 -1.751
F-16	101.740902 103.773	-1.536554 -12.988	-0.017743 -1.007	-0.086954 -1.469	-0.261857 -1.314
F/A-18	98.987526 19.418	-2.137920 -11.245	0.0284450 0.261	-0.125657 -0.737	-0.106498 -0.164

Table 4 summarizes the results of multiple regression using four independent variables. Associated with each coefficient is a t-value that indicates the level of significance of that coefficient. For the purposes of this study, the researchers have selected a value $\geq |1.0|$ to be significant.

The coefficient for each NMCS value detracts from the overall MC rate as indicated by its negative sign. A similar effect is achieved by the variable ABRT. In both of these cases the magnitude of the coefficient varies from one MDS to another. The remaining two variables show inconsistency between MDSS in both magnitude and sign.

The significance of NMCS is high in all models except the F-15. This is consistent with the results from the correlation analysis.

The variable HUTE appears to be significant to both the F-14 and F-16. This is shown by the relatively high t-value of each when compared to the t-value of the F-15 and F/A-18.

Both the F-14 and F-16 show a fairly high level of significance for the variable SUTE. However, the F-15 and F/A-18 t-values are almost as high as those of the F-14 and F-16. The variable SUTE contributes to the predicted MC rate of the F-14 but subtracts from the predicted MC rate of the other MDSSs.

The F-15 model exhibits the highest level of significance for the variable ABRT. The significance of the variable ABRT is extremely low in the F/A-18 regression model. The

remaining two MDS models exhibit a high level of significance for this variable.

Overall these findings are consistent with the correlation analysis throughout all MDSs' regression models.

Goodness-of-fit. The r-squared value indicates the amount of variability explained by the regression model. Three MDSs show fairly high r-squared values. One MDS, the F-15, has a lower r-squared value of 0.2805. The F-14, F-16 and F/A-18 all have an r-squared value of at least 0.8557. See Table 5 for a complete listing of all the full regression model r-squared values.

TABLE 5
GOODNESS-OF-FIT TESTS
(BY MDS)

<u>MDS</u>	<u>r-squared</u>	<u>F-Value</u>	<u>Prob > F</u>
F-14	0.8557	28.171	0.0001
F-15	0.2805	1.852	0.1606
F-16	0.9361	69.592	0.0001
F/A-18	0.8924	39.398	0.0001

The difference of the r-value from 1 accounts for the factors not included as independent variables that have a relationship with the dependent variable. The F-14, F-16 and F/A-18 all account for a large amount of factors bearing on the dependent variable MC. The F-14 regression equation accounts for 85.6% of the factors influencing MC. The F-16

regression accounts for 93.6% of the factors influencing MC. Finally, the F/A-18 regression accounts for 89.2% of the factors influencing its MC. The F-15 regression equation only accounts for 28.1% of the factors that influence the MC rate.

The F-statistic of the F-14, F-16 and F/A-18 show the regression models are useful for predicting MC rate at the 0.01 significance level. The F-15 model only shows usefulness at the 0.1 significance level. The values underneath the Prob > F column in Table 5 agree with the r-squared and F-statistic values in explaining the value of each regression model. In the F-15 model, there is a 16% probability that the model does not explain a significant portion of the variation in the data. There is a 99% probability that the remaining three regression models explain a significant portion of the data variation.

The final goodness-of-fit test used by the researchers was a visual analysis of the plot of residuals generated by the SAS program. Plots were obtained for each of the four full regression models. The visual examination shows that all four plots exhibited randomness. This validates the assumption that the error variance is constant over the range of the independent variables. The residual plots for all four full regression models are located in Appendix C.

Validation. The data sets were maintained in chronological order as received from their sources. The oldest data element in each set was numbered as the first

observation with the remaining elements being numbered sequentially.

The data sets were divided into two half-data sets, based on odd and even observations. These data sets were then subjected to double cross-validation techniques as outlined in Chapters II and III. Regression models were built for each half-data set using all four independent variables. Paired t-tests were performed between the actual MC rate and the predicted MC rate obtained from the opposite half-data set model.

The paired t-test between actual and predicted MC rates was evaluated with 99% confidence intervals. The confidence interval for each comparison pair included the value of zero. This indicates that there is no statistically significant difference between the two values. From the principles of double cross-validation, the researchers concluded the full 24 case regression models are valid. Table 6 summarizes the findings of the double cross-validation treatment, the full spreadsheet output is shown in Appendix E. The r-squared values of each half-data model closely approximate the r-squared value of the respective full regression models.

TABLE 6
DOUBLE CROSS-VALIDATION
(BY MDS)

<u>MDS</u>	<u>MEAN</u>	<u>STANDARD DEVIATION</u>	<u>UPPER C.I. 99%</u>	<u>LOWER C.I. 99%</u>	<u>r-squared</u>	<u>F-Value</u>
F-14						
EVEN	0.1024	3.1485	2.8791	-2.6743	0.8416	9.3
ODD	0.2149	2.0540	2.0263	-1.5965	0.9045	16.572
F-15						
EVEN	0.4239	0.8561	1.1789	-0.3311	0.2506	0.585
ODD	-0.4253	0.9273	0.3925	-1.2431	0.3950	1.143
F-16						
EVEN	-0.1644	0.5340	0.3065	-0.6353	0.9764	72.482
ODD	0.1014	0.3903	0.4456	-0.2428	0.9277	22.443
F/A-18						
EVEN	0.0303	1.1169	1.0153	-0.9547	0.9587	40.601
ODD	-0.2308	0.8557	0.5238	-0.9854	0.8891	14.026

Comparison Testing

The models developed have provided a means of predicting an organization's MC rate. The researchers have eliminated all known structural elements that contribute to the MC rate. These elements were eliminated for two reasons: 1) the researchers did not feel they could not identify and quantify all structural elements and, 2) the MMH data from HQ TAC was judged to be unreliable. Because they are specifically not included in the independent variables used, the structural factors that contribute to MC rate are contained in the error term of the regression model. MC rate was chosen as the comparison term because the error

term is difficult to relate to an organization's level of performance.

Two comparisons were made between the predicted MC rates of the F-15 and the F-14 and between the F-16 and F/A-18.

For the first test, each predicted MC rate for one MDS was compared to its corresponding MDS's predicted MC rate. This comparison was made with an uncorrelated paired t-test using 99% confidence intervals. See Table 7 for a summary of the results.

The confidence intervals do not include zero, therefore the researchers conclude there is a significant difference between the MC rates of the two services.

TABLE 7

PAIRED T-TESTS:
USAF PREDICTED MC RATES TO USN PREDICTED MC RATES
(BY MDS)

<u>MDS</u>	<u>MEAN</u>	<u>STANDARD DEVIATION</u>	<u>UPPER 99% C.I.</u>	<u>LOWER 99% C.I.</u>
F-15 TO F-14	21.2417	3.6126	23.3042	19.1791
F-16 TO F/A-18	20.5500	4.0579	22.8608	18.2332

The mean for the comparisons was calculated by subtracting the predicted USN MC rate from the predicted USAF MC rate. This resulted in positive values for both means. Positive values in this operation indicates that MC values for USAF aircraft are higher than those for

equivalent USN aircraft. The spreadsheet output for this test is shown in Appendix F.

For the second test, the independent variables from each MDS then were placed into the regression model developed for its comparison counterpart. This yielded a predicted MC based upon its comparison model for each observation. That is, the independent variables from the F-15 were placed into the regression model developed for the F-14. The predicted MC rate obtained from this step will be referred to as MC prime (MC').

The value, MC', was then subtracted from the original predicted MC rate to obtain a difference for use in the paired t-test. Again, 99% confidence intervals were established to provide consistency with the previous paired t-tests. The results of this test are summarized in Table 8. The full results from this test are shown in Appendix G.

The positive values of the mean and confidence intervals for the USAF aircraft indicate that higher levels of MC rate are achieved by using USAF data in the USAF regression models as opposed to using USAF data in the USN models. Additionally, negative values for the Navy aircraft indicate that higher MC rates are achieved for USN data when placed in USAF regression models.

The results from this test support the results from the first comparison test. The predicted MC rate achieved by using the USAF models for all four MDSs was significantly

greater than the predicted MC rate using the corresponding USN models.

TABLE 8
PAIRED T-TESTS:
CROSS COMPARISON OF PREDICTED VALUES
USAF vs. USN
(BY MDS)

<u>MDS</u>	<u>MEAN</u>	<u>STANDARD DEVIATION</u>	<u>UPPER 99% C.I.</u>	<u>LOWER 99% C.I.</u>
F-14 (USN) TO				
F-14 (AF)	-15.9896	3.4574	-14.0157	-17.9636
F-15 (AF) TO				
F-15 (USN)	8.8851	2.0395	10.0496	7.7207
F-16 (AF) TO				
F-16 (USN)	4.6461	0.7624	5.0814	4.2108
F/A-18 (USN) TO				
F/A-18 (AF)	-13.7677	0.8508	-13.2819	-14.2535

Chapter Summary

This chapter presented the results of the statistical analysis outlined in Chapter III. The researchers first re-examined the key maintenance indicators to determine if the indicators chosen in Chapter III contained elements of organizational structure, were duplicative or were unreliable. The independent variables selected for use in the analysis were NMCS, SUTE, HUTE and ABRT.

The four independent variables were then subjected to a correlation analysis using the SAS software package. An examination of the output revealed the relationship between the independent variables and the dependent variable, MC.

Stepwise regression yielded inconsistent results which prevented comparison between models. Because of this inconsistency, the researchers chose not to use the results of stepwise regression.

All four independent variables were used to develop regression models. Goodness-of-fit tests were performed to establish the significance of the overall models and the significance of each independent variable. All four regression models were validated by the double cross-validation method.

Finally, comparisons tests between data sets were performed. A paired t-test between predicted USAF and USN MC rates was performed to test which service produced higher results. To complete the comparison tests, data was exchanged from one MDS to its comparison MDS's model. The USAF models, with either USAF or USN data, consistently produced higher MC rates than USN models.

V. Conclusions and Recommendations

Introduction

This chapter will present conclusions the authors have formed in answer to the research questions outlined in Chapter I. Findings to the research questions follow a restatement of each question and are based on the methodology developed in Chapter III as well as the analyses and results presented in Chapter IV. Following the discussion of the research questions, an overall conclusion is presented. Recommendations for further study are offered at the end of this chapter.

Discussion

This section will list the research questions first presented in Chapter I. Specific findings will be listed following each question.

1. Can a model (either mathematical or analytical) be developed which can accurately predict an organization's performance as reflected in the MC rate? Regression modelling allowed an accurate and valid prediction of an organization's performance in three of four MDSs examined, as measured by MC rate. The models developed exhibited a high degree of correlation between the actual and predicted MC rate for 24 months of data. The one exception was the

model for the F-15 which only accounted for 28% of the known variability.

2. What variables contribute to the prediction of this maintenance performance? The researchers established a selection process to identify existing key maintenance indicators that directly contributed to MC rate, did not duplicate one another and did not contain structural influences.

The researchers performed two types of regression to answer this question. The first regression technique used the SAS stepwise feature. Stepwise regression produced inconsistent independent variables between the four MDSs. Stepwise regression selected NMCS and SUTE for the F-14 and F-16 models. The F-15 model used only the variable ABRT while the F/A-18 used only NMCS. The F-15 model is the only one that did not use NMCS; it is also the only model that did not accurately predict the dependent variable, MC rate.

The second regression technique used four independent variables in developing the models. From the list of key maintenance indicators supplied by HQ TAC and the Naval Sea Logistics Center, this process identified the following independent variables: Not Mission Capable, Supply (NMCS), Aircraft Hourly Utilization Rate (HUTE), Aircraft Sortie Utilization Rate (SUTE) and Abort Rate (ABRT). These independent variables were chosen by the researchers to account for non-structurally related influences. In addition, the four variables were used to provide

consistency among the four MDS's models to allow for comparison testing using the paired t-test procedure.

3. Are the variables in models of the USAF and USN organization's performance the same? Neither regression procedure showed consistency between the comparison pairs. The correlation matrix also showed inconsistencies in both the magnitude and direction of the independent variables to MC rate.

4. Do statistically significant differences exist between the levels of performance achieved by USAF and USN aircraft maintenance organizations as predicted by mathematical or analytical models? Based on the paired t-tests performed, the researchers conclude that there is a significant difference between the levels of performance achieved by the two different services. Consistently higher levels of performance were achieved by the models representing the pre-1992 USAF aircraft maintenance structure.

Conclusion

The researchers found that statistically significant differences exist between the performance levels of the USAF and USN aircraft maintenance organizations. These performance levels are measured by the MC rate. The researchers found that the maintenance organization represented by the USAF regression models are capable of

producing consistently higher levels of performance than the organization represented by the USN models. Thus, the pre-1992 (COMO) organizational structure appears to be capable of producing significantly superior performance than post-1992 (Objective Wing) structures.

This study has focused on the structural differences between two aircraft maintenance organizations, the USAF and the USN, and their ability to produce mission capability. The researchers acknowledge there are many influences that may account for this difference in performance other than organizational structure alone. The following factors may contribute to performance differences:

1. Difficulties of maintaining aircraft while deployed at sea: lack of easy access to the logistics repair pipeline, increased corrosion potential, space limitation aboard the carrier and fewer airframes available to support the flying schedule.

2. Mission differences between the services.

3. A violation of the researcher's first assumption concerning the data provided. It is possible that some key maintenance indicators are inflated or deflated for reporting purposes.

4. The maintainability and reliability inherent in the design of the MDS.

5. The skill/education level of the technician for which the MDS was designed.

6. The planned maintenance concept and the planned organizational structure of the MDS.

7. Adequacy and depth of the spares provisioning.

8. The corporate philosophy of the maintainers.

Recommendations

1. A qualitative study comparing the aircraft maintenance structures of the pre-1992 organization and the post-1992 organization should be accomplished. This study should identify those advantages of each structure that will better support the new Air Force mission.

2. A statistical study should be performed of key maintenance indicators at one location using pre-1992 data vs. data from the same organization while under the post-1992 maintenance structure. The unit should be selected so that the only difference between the two data sets is the change in organizational structure. This should yield an accurate comparison of a pre- and post-1992 organization.

3. Reaccomplish the study outlined in this thesis with the exception of using independent variables that contain structural influences and allow all other influences to be included in the error term.

4. Expand the study to include additional maintenance organizations. The researchers attempted to include the RAF and Canadian Forces, Air Command but were unable to because

these services classify their key maintenance indicators. As outlined in Chapter II, the RAF maintenance structure is similar to the new USAF post-1992 maintenance structure and the Canadian structure is similar to the pre-1992 USAF structure. The inclusion of more services would present a larger population from which to draw a conclusion.

Summary

The researchers analyzed two different aircraft maintenance organizations representing two different organizational structures used by the USAF. This analysis attempted to establish whether one of the two structures produces higher levels of performance than the other. The measure of performance used in this study was MC rate.

Using multiple regression and paired t-tests, the structure represented by pre-1992 USAF aircraft maintenance consistently produced higher levels of performance than the structure representing the post-1992 aircraft maintenance structure. The post-1992 aircraft maintenance structure was represented by the aircraft maintenance structure of USN aviation units deployed at sea.

Several recommendations were made to expand and improve the findings of this study. Each recommended study would assist in establishing advantages of one structure over another as it relates to mission accomplishment.

Appendix A: Maintenance Data

F-14 Data Set

<u>OBS</u>	<u>MC</u>	<u>NMCS</u>	<u>SUTE</u>	<u>HUTE</u>	<u>ABRT</u>
1	70.4	10.0	18.4	29.0	7.03
2	66.3	11.9	19.9	32.0	7.83
3	66.2	13.1	18.6	29.7	6.85
4	59.5	13.7	19.7	32.0	7.87
5	70.0	9.4	17.4	26.1	7.20
6	66.2	10.0	14.0	23.0	7.76
7	68.5	9.0	20.7	32.7	7.13
8	68.0	10.1	17.3	27.7	6.90
9	69.4	8.9	19.3	30.8	6.94
10	64.3	11.3	16.8	26.9	7.47
11	63.9	13.7	17.9	28.4	6.19
12	58.7	14.1	16.7	25.9	6.83
13	56.9	13.5	14.8	23.5	6.87
14	60.4	13.7	18.1	28.8	7.12
15	61.6	13.7	17.5	29.3	5.42
16	55.2	17.3	16.7	30.2	6.04
17	58.7	15.4	16.8	27.5	6.02
18	62.5	13.0	14.6	25.5	5.24
19	60.8	14.0	21.3	42.2	7.17
20	59.1	15.1	20.6	47.3	6.16
21	63.7	13.1	17.6	30.9	7.17
22	62.5	14.1	17.8	28.3	7.17
23	60.8	13.8	17.7	29.6	6.85
24	62.5	12.7	17.1	28.8	6.33

F-15 Data Set

<u>OBS</u>	<u>MC</u>	<u>NMCS</u>	<u>SUTE</u>	<u>HUTE</u>	<u>ABRT</u>
1	84.2	7.2	20.75	29.73	3.8
2	83.0	8.7	19.00	25.77	5.3
3	83.8	8.8	16.43	20.99	4.4
4	84.5	8.7	20.94	27.03	3.6
5	85.5	7.8	19.28	24.45	4.0
6	85.8	7.0	21.45	29.27	4.0
7	86.2	6.5	21.94	29.86	3.5
8	86.0	7.5	20.72	26.13	3.6
9	84.2	7.5	21.28	28.72	2.9
10	84.4	7.3	20.33	28.12	4.2
11	81.7	6.6	19.17	33.85	4.2
12	84.2	6.0	17.27	25.50	4.1
13	82.0	7.9	19.94	34.29	4.7
14	82.3	7.4	19.54	34.07	4.3
15	85.5	7.4	17.14	30.29	3.9
16	83.9	8.2	22.84	60.68	5.2
17	83.9	8.0	20.95	66.34	4.9
18	87.2	6.3	17.94	38.94	3.3
19	84.6	6.8	18.58	28.13	4.3
20	85.5	6.7	19.75	26.47	4.5
21	84.1	7.0	19.82	27.77	4.7
22	84.8	7.7	20.95	29.82	4.8
23	82.8	10.0	20.14	28.06	4.4
24	85.8	7.8	12.97	16.76	4.5

F-16 Data Set

<u>OBS</u>	<u>MC</u>	<u>NMCS</u>	<u>SUTE</u>	<u>HUTE</u>	<u>ABRT</u>
1	88.3	6.3	31.64	21.17	4.1
2	89.0	5.8	28.29	20.08	4.9
3	89.0	6.3	25.27	18.19	5.1
4	88.3	6.9	30.44	21.38	3.8
5	88.4	6.8	26.94	17.76	3.8
6	90.1	4.9	31.68	21.39	4.0
7	90.8	4.6	31.57	21.89	3.4
8	90.2	5.0	29.80	20.18	3.1
9	88.9	6.1	31.83	20.97	2.9
10	90.9	5.1	30.65	21.16	3.6
11	91.1	4.9	32.09	19.51	3.8
12	91.0	4.8	27.08	16.99	4.4
13	92.3	4.5	33.14	20.52	3.9
14	92.7	4.3	32.89	19.13	3.4
15	93.3	4.0	31.34	17.66	3.8
16	90.2	4.5	52.37	20.68	4.4
17	90.0	4.8	68.07	28.63	3.6
18	93.0	4.2	26.17	12.70	2.9
19	94.7	2.8	23.29	15.42	3.3
20	93.5	3.4	25.58	17.43	3.8
21	92.0	4.4	26.93	19.39	3.4
22	92.5	4.0	27.31	19.67	3.9
23	91.2	4.6	30.95	20.50	4.3
24	92.0	4.4	21.38	15.14	3.7

F/A-18 Data Set

<u>OBS</u>	<u>MC</u>	<u>NMCS</u>	<u>SUTE</u>	<u>HUTE</u>	<u>ABRT</u>
1	74.7	9.3	27.4	37.7	4.68
2	71.4	10.9	35.3	47.5	3.70
3	74.3	9.7	26.5	36.9	3.77
4	76.6	9.5	30.4	43.5	3.69
5	74.1	10.5	27.4	36.0	3.68
6	73.8	11.1	24.2	32.0	3.48
7	72.1	11.0	29.9	39.0	3.61
8	71.5	11.2	29.8	40.3	4.45
9	72.8	10.3	33.0	46.0	3.95
10	64.8	13.3	26.7	36.2	3.40
11	69.3	12.4	27.9	37.3	3.55
12	68.5	11.9	26.3	34.7	4.04
13	68.4	12.8	25.8	34.0	4.02
14	66.1	14.2	25.8	34.1	4.46
15	66.7	13.1	22.1	30.1	4.63
16	67.6	13.4	28.8	38.3	4.01
17	67.3	13.9	24.6	34.8	4.13
18	67.8	13.3	21.8	31.0	4.30
19	72.0	11.4	25.2	40.9	4.96
20	71.2	11.3	27.9	46.6	4.15
21	69.0	12.4	21.7	29.9	4.13
22	71.2	11.6	22.2	31.6	4.57
23	67.3	12.9	25.5	35.8	4.36
24	71.7	11.9	23.9	33.4	4.66

Appendix B

Sample SAS Program

```
options linesize=80;
data mxstats;
infile "MDS.dat";
input mc nmcs hute sute abrt;

proc corr;
var mc nmcs hute sute abrt;
title '(MDS) Correlation Analysis';
run;

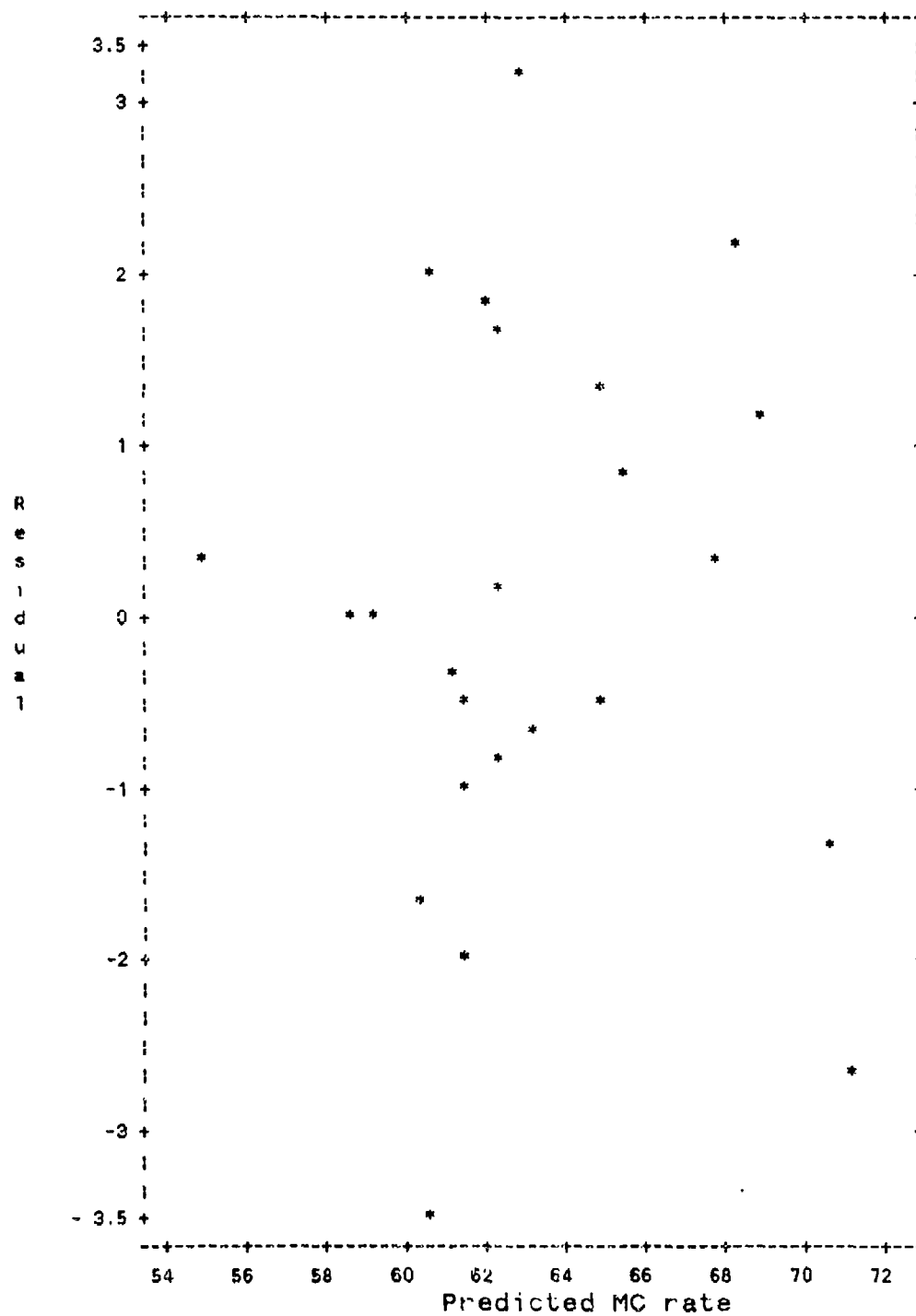
proc stepwise;
model mc=nmcs hute sute abrt;
title '(MDS) Stepwise Regression';

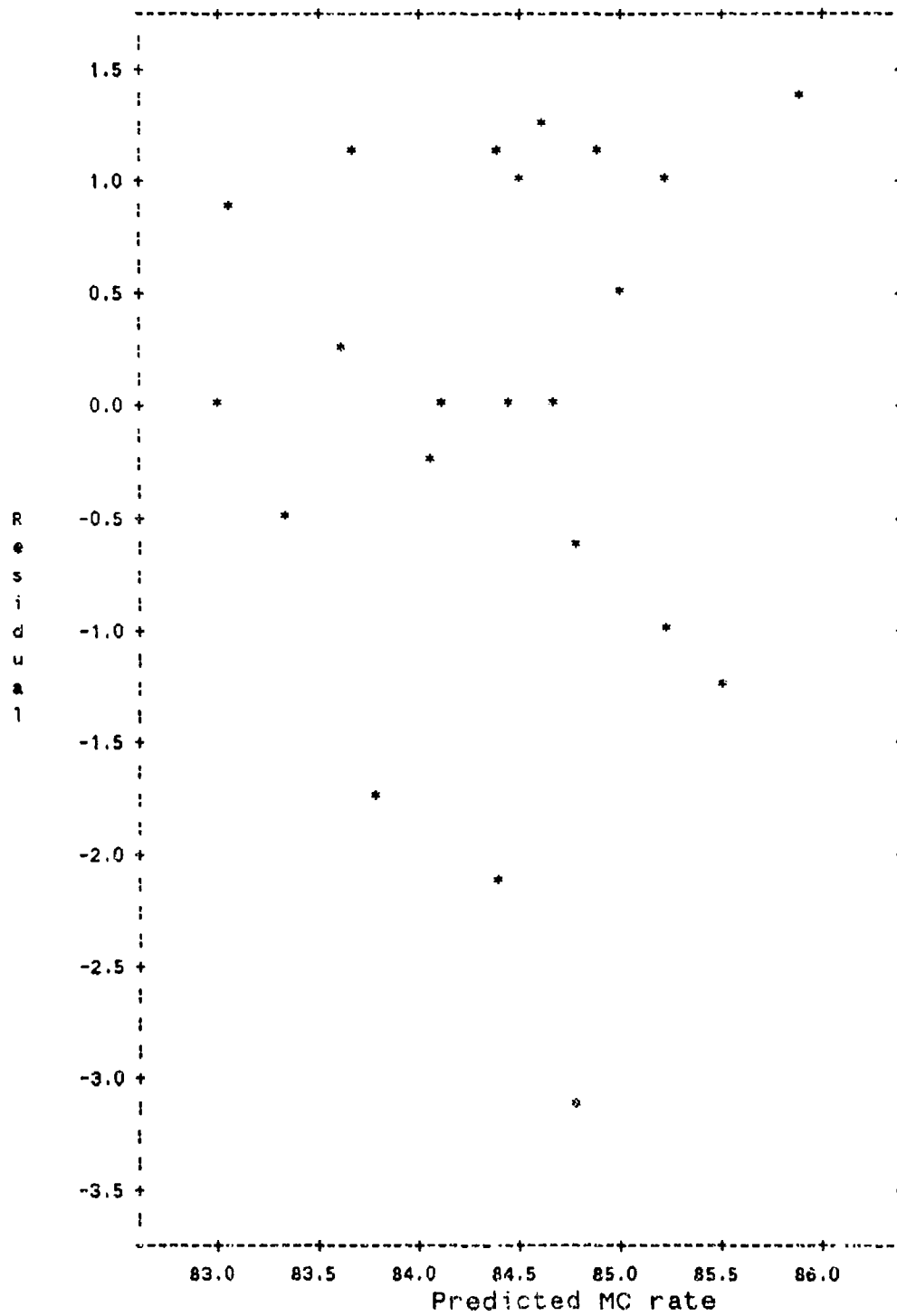
proc reg;
model mc=nmcs hute sute abrt/p;
title '(MDS) Regression Model';
plot residual.*predicted.='*';
print cli;

proc glm;
model mc=nmcs hute sute abrt/alpha=.01 cli;
title '(MDS) 99% Prediction Limits';
run;
```

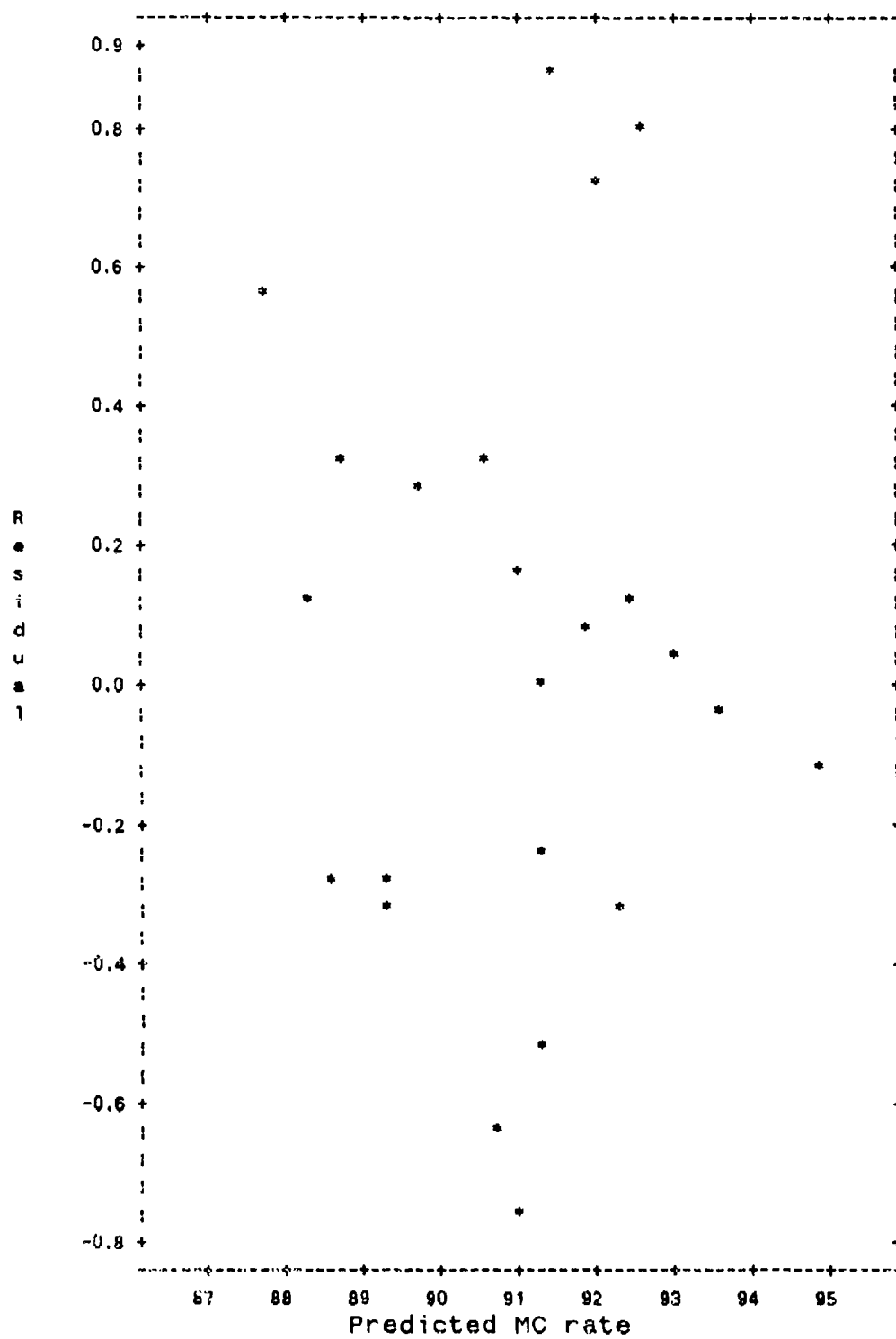
Appendix C: Plot of Residuals

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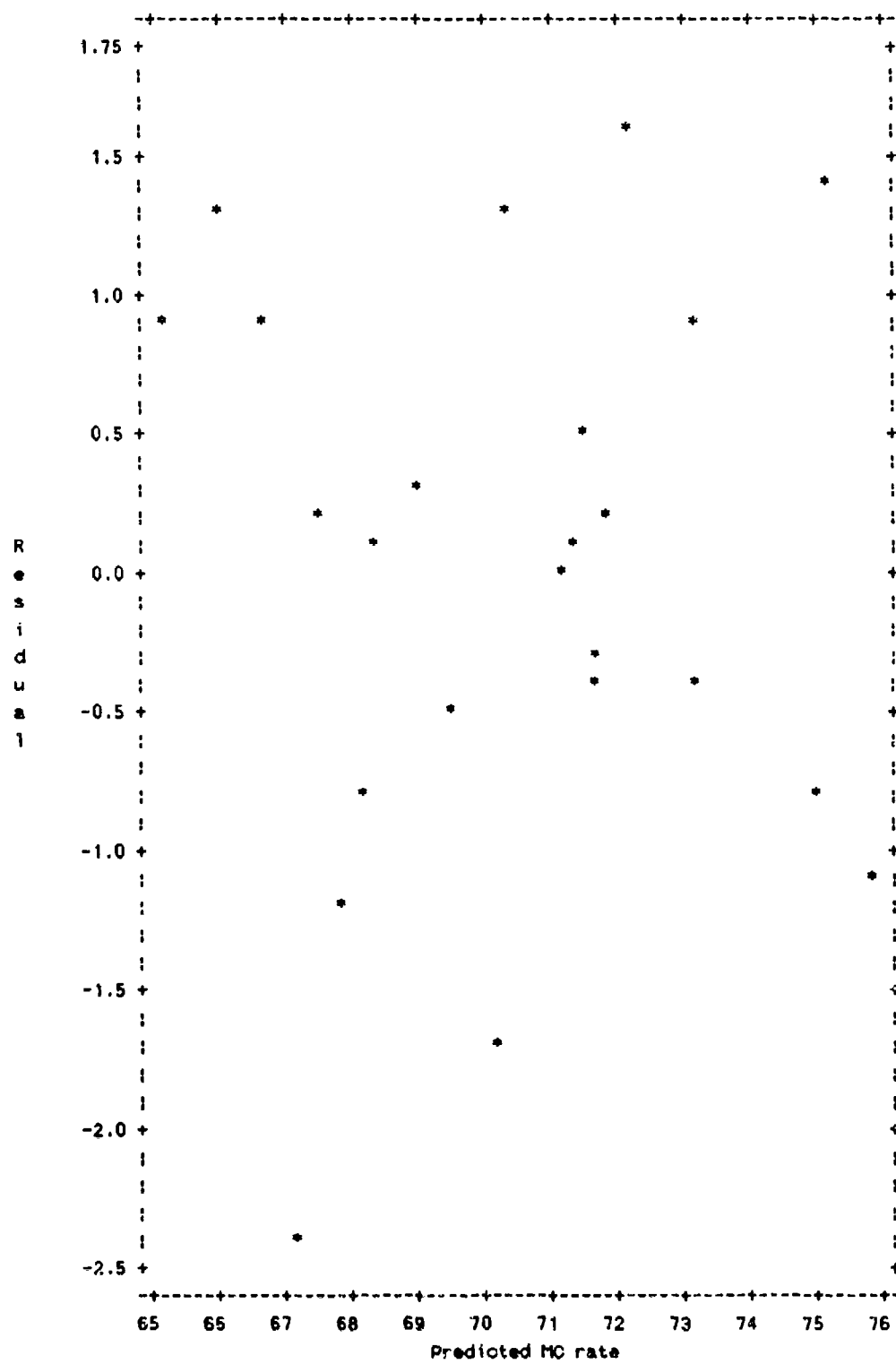




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Appendix D: SAS Outputs

F-14 Correlation Analysis

Correlation Analysis

5 'VAR' Variables: MC NMCS HUTE SUTE ABRT

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
MC	24	63.1708	4.2491	1516	55.2000	70.4000
NMCS	24	12.6917	2.1773	304.6000	8.9000	17.3000
HUTE	24	29.8375	5.2710	716.1000	23.0000	47.3000
SUTE	24	17.8042	1.8534	427.3000	14.0000	21.3000
ABRT	24	6.8150	0.6907	163.5600	5.2400	7.9700

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 24

	MC	NMCS	HUTE	SUTE	ABRT
MC	1.00000 0.0	-0.90575 0.0001	-0.14234 0.5070	0.18275 0.3927	0.34586 0.0978
NMCS	-0.90575 0.0001	1.00000 0.0	0.24741 0.2438	-0.05074 0.8139	-0.43918 0.0318
HUTE	-0.14234 0.5070	0.24741 0.2438	1.00000 0.0	0.80480 0.0001	-0.02487 0.9082
SUTE	0.18275 0.3927	-0.05074 0.8139	0.80480 0.0001	1.00000 0.0	0.25739 0.2247
ABRT	0.34586 0.0978	-0.43918 0.0318	-0.02487 0.9082	0.25739 0.2247	1.00000 0.0

F-14 Stepwise Regression

Stepwise Procedure for Dependent Variable MC

Step 1 Variable NMCS Entered R-square = 0.82038102 C(p) = 3.65266342

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	340.67928512	340.67928512	100.48	0.0001
Error	22	74.59029821	3.39046810		
Total	23	415.26958333			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	85.60458554	2.26933601	4824.54222632	1422.97	0.0001
NMCS	-1.76759702	0.17633569	340.67928512	100.48	0.0001

Bounds on condition number: 1, 1

Step 2 Variable SUTE Entered R-square = 0.83914294 C(p) = 3.18204812

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	348.47054010	174.23527005	54.78	0.0001
Error	21	66.79904323	3.18090682		
Total	23	415.26958333			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	79.83407915	4.29259034	1100.24321988	345.89	0.0001
NMCS	-1.75401738	0.17101947	334.60129734	105.19	0.0001
SUTE	0.31442966	0.20090709	7.79125498	2.45	0.1325

Bounds on condition number: 1.002581, 4.010323

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable MC

Step	Variable Entered	Number Removed	In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	NMCS		1	0.8204	0.8204	3.6527	100.4815	0.0001
2	SUTE		2	0.0198	0.8391	3.1820	2.4494	0.1325

F-14 Regression Model

Model: MODEL1

Dependent Variable: MC

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	355.35178	88.83794	28.171	0.0001
Error	19	59.91780	3.15357		
C Total	23	415.26958			
Root MSE	1.77583	R-square	0.8557		
Dep Mean	63.17083	Adj R-sq	0.8253		
C.V.	2.8115				

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	82.898637	6.32890697	13.098	0.0001
MMCS	1	-1.772915	0.20471805	-8.660	0.0001
MUTE	1	-0.135422	0.13960198	-0.970	0.3442
SUTE	1	0.703684	0.39726070	1.771	0.0925
ABRT	1	-0.838504	0.63728724	-1.316	0.2039

F-14 Regression Model

Obs	Dep Var MC	Predict Value	Residual
1	70.4000	68.2953	2.1047
2	66.3000	64.9053	1.3947
3	66.2000	62.9962	3.2038
4	59.5000	61.5397	-2.0397
5	70.0000	68.9056	1.0944
6	66.2000	65.3996	0.8004
7	68.5000	71.1018	-2.6018
8	68.0000	67.6291	0.3709
9	69.4000	70.7106	-1.3106
10	64.3000	64.7801	-0.4801
11	63.9000	62.1693	1.7307
12	58.7000	60.4176	-1.7176
13	56.9000	60.4359	-3.5359
14	60.4000	61.4761	-1.0761
15	61.6000	62.4116	-0.8116
16	55.2000	54.8244	0.3756
17	58.7000	58.6457	0.0543
18	62.5000	62.2775	0.2225
19	60.8000	61.3394	-0.5394
20	59.1000	59.0529	0.0471
21	63.7000	61.8617	1.8383
22	62.5000	60.5016	1.9184
23	60.8000	61.1354	-0.3354
24	62.5000	63.2077	-0.7077

Sum of Residuals	0
Sum of Squared Residuals	59.9178
Predicted Resid SS (Press)	89.9274

F-14 Regression Model

Obs	Dep Var MC	Predict Value	Std Err Predict	Lower95% Predict	Upper95% Predict	Residual
1	70.4000	68.2953	0.610	64.3654	72.2253	2.1047
2	66.3000	64.9053	0.746	60.8739	68.9366	1.3947
3	66.2000	62.9962	0.512	59.1280	66.8643	3.2038
4	59.5000	61.5397	0.882	57.3896	65.6899	-2.0397
5	70.0000	68.9056	0.680	64.9257	72.8855	1.0944
6	66.2000	65.3996	1.322	60.7659	70.0332	0.8004
7	68.5000	71.1018	0.981	66.8560	75.3476	-2.6018
8	68.0000	67.6291	0.606	63.7020	71.5561	0.3709
9	69.4000	70.7106	0.852	66.5883	74.3329	-1.3106
10	64.3000	64.7801	0.608	60.8516	68.7086	-0.4801
11	63.9000	62.1693	0.649	58.2118	66.1268	1.7307
12	58.7000	60.4176	0.589	56.5019	64.3333	-1.7176
13	56.9000	60.4359	0.761	56.3918	64.4799	-3.5359
14	60.4000	61.4761	0.554	57.5823	65.3698	-1.0761
15	61.6000	62.4116	0.902	58.2429	66.5804	-0.8116
16	55.2000	54.8244	0.884	50.6723	58.9765	0.3756
17	58.7000	58.6457	0.721	54.6345	62.6570	0.0543
18	62.5000	62.2775	1.089	57.9173	66.6377	0.2225
19	60.8000	61.3394	0.975	57.0991	65.5797	-0.5394
20	59.1000	59.0529	1.487	54.2048	63.9012	0.0471
21	63.7000	61.8617	0.516	57.9914	65.7320	1.8383
22	62.5000	60.5816	0.612	56.6505	64.5126	1.9184
23	60.8000	61.1354	0.433	57.3096	64.9611	-0.3354
24	62.5000	63.2077	0.469	59.3636	67.0518	-0.7077

Sum of Residuals 0
Sum of Squared Residuals 59.9178
Predicted Resid SS (Press) 89.9274

F-14 99% Prediction Limits

General Linear Models Procedure

Dependent Variable: MC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	355.35177868	88.83794467	28.17	0.0001
Error	19	59.91780465	3.15356867		
Corrected Total	23	415.26958333			

R-Square	C.V.	Root MSE	MC Mean
0.855713	2.811153	1.7758290	63.170833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
NMCS	1	340.67928512	340.67928512	108.03	0.0001
HUTE	1	2.95641263	2.95641263	0.94	0.3451
SUTE	1	6.25671457	6.25671457	1.98	0.1751
ABRT	1	5.45936637	5.45936637	1.73	0.2039

Source	DF	Type III SS	Mean Square	F Value	Pr > F
NMCS	1	236.51895759	236.51895759	75.00	0.0001
HUTE	1	2.96754217	2.96754217	0.94	0.3442
SUTE	1	9.89477810	9.89477810	3.14	0.0925
ABRT	1	5.45936637	5.45936637	1.73	0.2039

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	82.89863693	13.10	0.0001	6.32890697
NMCS	-1.77291521	-8.66	0.0001	0.20471805
HUTE	-0.13542190	-0.97	0.3442	0.13960199
SUTE	0.70368370	1.77	0.0925	0.39726070
ABRT	-0.83850412	-1.32	0.2039	0.63728724

F-14 Regression Model

Observation	Observed	Predicted Residual	Lower 99% C.L. Upper 99% C.L.
1	70.40000000	68.29534577 2.10465423	62.92346852 73.66722302
2	66.30000000	64.90526342 1.39473658	59.39479016 70.41573668
3	66.20000000	62.99618077 3.20381923	57.70879336 68.28356817
4	59.50000000	61.53973913 -2.03973913	55.86682910 67.21204917
5	70.00000000	68.90558901 1.09441099	63.46539870 74.34577933
6	66.20000000	65.38956090 0.80043910	59.06573610 71.73338570
7	68.50000000	71.10182204 -2.60182204	65.29818771 76.90545637
8	68.00000000	67.62905619 0.37094381	62.26113771 72.99697467
9	69.40000000	70.71057378 -1.31057378	65.07578116 76.34536640
10	64.30000000	64.78010626 -0.48010626	59.41021436 70.14999816
11	63.90000000	62.16931424 1.73068576	56.75981787 67.57881061
12	58.70000000	60.41763984 -1.71763984	55.06523485 65.77004482
13	56.90000000	60.43586234 -3.53586234	54.90806027 65.96366440
14	60.40000000	61.47607339 -1.07607339	56.15370289 66.79844389
15	61.60000000	62.41160922 -0.81160922	56.71331633 68.10990212
16	55.20000000	54.82441524 0.37558476	49.14890510 60.49992538
17	58.70000000	58.64573173 0.05426827	53.16273711 64.12872634
18	62.50000000	62.27750111 0.22249889	56.31746571 68.23753651
19	60.80000000	61.33940797 -0.53940797	55.54336015 67.13545580
20	59.10000000	59.05286011 0.04713989	52.42566546 65.68005476
21	63.70000000	61.86166947 1.83833053	56.57133177 67.15200717
22	62.50000000	60.58158794 1.91841206	55.20819049 65.95498540
23	60.80000000	61.13536698 -0.33536698	55.90594587 66.36478809
24	62.50000000	63.20772316 -0.70772316	57.95320541 68.46224090

F-14 Regression Model

Sum of Residuals	-0.00000000
Sum of Squared Residuals	59.91780465
Sum of Squared Residuals - Error SS	0.00000000
Press Statistic	89.92738124
First Order Autocorrelation	0.10590208
Durbin-Watson D	1.70590910

F-15 Correlation Analysis

Correlation Analysis

5 'VAR' Variables: MC NMCS HUTE SUTE ABRT

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
MC	24	84.4125	1.3901	2026	81.7000	87.2000
NMCS	24	7.5333	0.9135	180.8000	6.0000	10.0000
HUTE	24	19.5467	2.0967	469.1200	12.9700	22.8400
SUTE	24	31.2933	10.8973	751.0400	16.7600	66.3400
ABRT	24	4.2125	0.5856	101.1000	2.9000	5.3000

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 24

	MC	NMCS	HUTE	SUTE	ABRT
MC	1.00000 0.0	-0.37388 0.0719	-0.11717 0.5856	-0.16706 0.4352	-0.46222 0.0230
NMCS	-0.37388 0.0719	1.00000 0.0	0.05170 0.8104	0.03399 0.8747	0.35439 0.0893
HUTE	-0.11717 0.5856	0.05170 0.8104	1.00000 0.0	0.47770 0.0182	-0.05475 0.7994
SUTE	-0.16706 0.4352	0.03399 0.8747	0.47770 0.0182	1.00000 0.0	0.30352 0.1494
ABRT	-0.46222 0.0230	0.35439 0.0893	-0.05475 0.7994	0.30352 0.1494	1.00000 0.0

F-15 Stepwise Regression

Stepwise Procedure for Dependent Variable MC

Step 1 Variable ABRT Entered R-square = 0.21365006 C(p) = 0.76618106

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	9.49594409	9.49594409	5.98	0.0230
Error	22	34.95030591	1.58865027		
Total	23	44.44625000			

Variable	Parameter Estimate	Standard Error	Type III Sum of Squares	F	Prob>F
INTERCEP	89.03496592	1.90810828	3458.94346175	2177.28	0.0001
ABRT	-1.09732129	0.44882690	9.49594409	5.98	0.0230

Bounds on condition number: 1, 1

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable MC

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	ABRT		1	0.2137	0.2137	0.7662	5.9774	0.0230

F-15 Regression Model

Model: MODEL1

Dependent Variable: MC

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	12.46850	3.11712	1.852	0.1606
Error	19	31.97775	1.68304		
C Total	23	44.44625			
Root MSE	1.29732	R-square	0.2805		
Dep Mean	84.41250	Adj R-sq	0.1291		
C.V.	1.53688				

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	92.706294	3.77854210	24.535	0.0001
NMCS	1	-0.344407	0.32091272	-1.073	0.2966
HUTE	1	-0.093590	0.15272488	-0.613	0.5473
SUTE	1	0.003704	0.03080959	0.120	0.9056
ABRT	1	-0.946179	0.54030253	-1.751	0.0960

F-15 Regression Model

Obs	Dep Var MC	Predict Value	Residual
1	84.2000	84.7992	-0.5992
2	83.0000	83.0124	-0.0124
3	83.8000	84.0524	-0.2524
4	84.5000	84.4440	0.0560
5	85.5000	84.5213	0.9787
6	85.8000	84.6116	1.1884
7	86.2000	85.2132	0.9868
8	86.0000	84.8746	1.1254
9	84.2000	85.4941	-1.2941
10	84.4000	84.4196	-0.0196
11	81.7000	84.7905	-3.0905
12	84.2000	85.2387	-1.0387
13	82.0000	83.7992	-1.7992
14	82.3000	84.3865	-2.0865
15	85.5000	84.9756	0.5244
16	83.9000	83.0432	0.8508
17	83.9000	83.5997	0.3003
18	87.2000	85.8793	1.3207
19	84.6000	84.6610	-0.0610
20	85.5000	84.3906	1.1094
21	84.1000	84.0963	0.00371
22	84.8000	83.6624	1.1376
23	82.8000	83.3180	-0.5180
24	85.8000	84.6103	1.1897

Sum of Residuals	0
Sum of Squared Residuals	31.9778
Predicted Resid SS (Press)	48.7079

F-15 Regression Model

Obs	Dep Var MC	Predict Value	Std Err Predict	Lower95% Predict	Upper95% Predict	Residual
1	84.2000	84.7892	0.367	81.9774	87.6210	-0.5992
2	83.0000	83.0124	0.672	79.9544	86.0705	-0.0124
3	83.8000	84.0524	0.631	81.0330	87.0718	-0.2524
4	84.5000	84.4440	0.630	81.4252	87.4629	0.0560
5	85.5000	84.5213	0.338	81.7154	87.3273	0.9787
6	85.8000	84.6116	0.445	81.7408	87.4824	1.1884
7	86.2000	85.2132	0.576	82.2426	88.1839	0.9868
8	86.0000	84.8746	0.438	82.0090	87.7402	1.1254
9	84.2000	85.4541	0.721	82.3874	88.6007	-1.2941
10	84.4000	84.4196	0.340	81.6129	87.2264	-0.0196
11	81.7000	84.7905	0.402	81.9477	87.6332	-3.0905
12	84.2000	85.2387	0.600	82.2468	88.2305	-1.0387
13	82.0000	83.7992	0.355	80.9839	86.6146	-1.7992
14	82.3000	84.3865	0.281	81.6084	87.1647	-2.0865
15	85.5000	84.9756	0.494	82.0698	87.8815	0.5244
16	83.9000	83.0492	0.831	79.8247	86.2736	0.8508
17	83.9000	83.5997	0.957	80.2255	86.9739	0.3003
18	87.2000	85.9793	0.776	82.7155	89.0432	1.3207
19	84.6000	84.6610	0.386	81.8280	87.4940	-0.0610
20	85.5000	84.3906	0.510	81.4729	87.3082	1.1094
21	84.1000	84.0963	0.508	81.1805	87.0121	0.00371
22	84.8000	83.6624	0.513	80.7422	86.5826	1.1376
23	82.8000	83.3180	0.802	80.1254	86.5107	-0.5180
24	85.8000	84.6103	0.899	81.3066	87.9140	1.1897

Sum of Residuals 0
Sum of Squared Residuals 31.9778
Predicted Resid SS (Press) 48.7079

F-15 99% Prediction Limits

General Linear Models Procedure

Number of observations in data set = 24

Dependent Variable: MC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	12.46849682	3.11712421	1.85	0.1606
Error	19	31.97775318	1.68303964		
Corrected Total	23	44.44625000			
	R-Square	C.V.	Root MSE	MC Mean	
	0.280530	1.536882	1.2973202	84.412500	

Source	DF	Type I SS	Mean Square	F Value	Pr > F
NMCS	1	6.21290726	6.21290726	3.69	0.0698
HUTE	1	0.42663247	0.42663247	0.25	0.6204
SUTE	1	0.66756680	0.66756680	0.40	0.5363
ABRT	1	5.16139030	5.16139030	3.07	0.0960

Source	DF	Type III SS	Mean Square	F Value	Pr > F
NMCS	1	1.93849202	1.93849202	1.15	0.2966
HUTE	1	0.63203019	0.63203019	0.38	0.5473
SUTE	1	0.02431984	0.02431984	0.01	0.9056
ABRT	1	5.16139030	5.16139030	3.07	0.0960

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	92.70629402	24.53	0.0001	3.77854210
NMCS	-0.34440684	-1.07	0.2966	0.32091272
HUTE	-0.09359045	-0.61	0.5473	0.15272498
SUTE	0.00370356	0.12	0.9056	0.03080959
ABRT	-0.54617873	-1.75	0.0960	0.54030253

F-15 Regression Model

Observation	Observed	Predicted Residual	Lower 99% CL Upper 99% CL
1	84.20000000	84.79919060 -0.59919060	80.94202384 88.65635737
2	83.00000000	83.01242946 -0.01242946	78.83232731 87.19253160
3	83.80000000	84.05237407 -0.25237407	79.92514061 88.17960753
4	84.50000000	84.44403430 0.05596570	80.31750341 88.57056520
5	85.50000000	84.52133393 0.97866607	80.68588811 88.35677975
6	85.80000000	84.61161928 1.18838072	80.68751557 88.53572298
7	86.20000000	85.21323784 0.98676216	81.15267680 89.27379868
8	86.00000000	84.87457921 1.12542079	80.95756645 88.79159196
9	84.20000000	85.49408588 -1.29408588	81.24758563 89.74058613
10	84.40000000	84.41962369 -0.01962369	80.58304337 86.25620401
11	81.70000000	84.79049478 -3.09049478	80.90471646 88.67627309
12	84.20000000	85.23865390 -1.03865390	81.14902003 89.32828777
13	82.00000000	83.79924145 -1.79924145	79.95095440 87.64752850
14	82.30000000	84.38653775 -2.08653775	80.58902986 88.18404565
15	85.50000000	84.97562687 0.52437313	81.00357319 88.94768055
16	83.90000000	83.04915461 0.85084539	78.64162625 87.45668297
17	83.90000000	83.59973767 0.30026233	78.98751874 88.21195661
18	87.20000000	85.87934504 1.32065496	81.55464412 90.20404596
19	84.60000000	84.66102956 -0.06102956	80.78858908 88.53347003
20	85.50000000	84.39058577 1.10941423	80.40240993 88.37876160
21	84.10000000	84.09629126 0.00370874	80.11070781 88.08187471
22	84.80000000	83.66242369 1.13757631	79.67074507 87.65410231
23	82.80000000	83.31804946 -0.51804946	78.95401980 87.68207912
24	85.80000000	84.61031994 1.18968006	80.09447120 89.12616868

F-15 Regression Model

Sum of Residuals	-0.00000000
Sum of Squared Residuals	31.97775318
Sum of Squared Residuals - Error SS	0.00000000
Press Statistic	48.70785746
First Order Autocorrelation	0.30078600
Durbin-Watson D	1.34294043

F-16 Correlation Analysis

5 'VAR' Variables: MC NMCS HUTE SUTE ABRT

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
MC	24	90.9750	1.8056	2183	88.3000	94.7000
NMCS	24	4.8917	1.0210	117.4000	2.8000	6.9000
HUTE	24	31.5338	9.6541	756.8100	21.3800	68.0700
SUTE	24	19.4808	3.0137	467.5400	12.7000	28.6300
ABRT	24	3.8042	0.5497	91.3000	2.9000	5.1000

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 24

	MC	NMCS	HUTE	SUTE	ABRT
MC	1.00000 0.0	-0.93873 0.0001	-0.22965 0.2804	-0.48805 0.0155	-0.34902 0.0946
NMCS	-0.93873 0.0001	1.00000 0.0	0.02643 0.9024	0.30342 0.1495	0.29211 0.1660
HUTE	-0.22965 0.2804	0.02643 0.9024	1.00000 0.0	0.75824 0.0001	0.02227 0.9177
SUTE	-0.43805 0.0155	0.30342 0.1495	0.75824 0.0001	1.00000 0.0	0.09217 0.6684
ABRT	-0.34902 0.0946	0.29211 0.1660	0.02227 0.9177	0.09217 0.6684	1.00000 0.0

F-16 Stepwise Regression

Stepwise Procedure for Dependent Variable MC

Step 1 Variable NMCS Entered R-square = 0.88121497 C(p) = 15.32274192

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	66.07790471	66.07790471	163.21	0.0001
Error	22	8.90709529	0.40486797		
Total	23	74.98500000			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	99.09536387	0.64876375	9445.97825957	23331.0	0.0001
NMCS	-1.66004031	0.12994130	66.07790471	163.21	0.0001

Bounds on condition number: 1, 1

Step 2 Variable SUTE Entered R-square = 0.92670286 C(p) = 3.79614599

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	69.48881429	34.74440714	132.75	0.0001
Error	21	5.49618571	0.26172313		
Total	23	74.98500000			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	101.12036089	0.76598182	4561.23448468	17427.7	0.0001
NMCS	-1.53994003	0.10964379	51.62756492	197.26	0.0001
SUTE	-0.13410553	0.03714776	3.41090958	13.03	0.0016

Bounds on condition number: 1.1014, 4.405599

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable MC

Step	Variable Entered	Number Removed	In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	NMCS		1	0.8812	0.8812	15.3227	163.2085	0.0001
2	SUTE		2	0.0455	0.9267	3.7961	13.0325	0.0016

F-16 Regression Model

Model: MODEL1

Dependent Variable: MC

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	70.19390	17.54847	69.592	0.0001
Error	19	4.79110	0.25216		
C Total	23	74.98500			
Root MSE		0.50216	R-square	0.9361	
Dep Mean		90.97500	Adj R-sq	0.9227	
C.V.		0.55197			

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	101.740902	0.98041890	103.773	0.0001
NMCS	1	-1.536554	0.11830918	-12.988	0.0001
HUTE	1	-0.017743	0.01761172	-1.007	0.3264
SUTE	1	-0.086954	0.05918199	-1.469	0.1581
ABRT	1	-0.261857	0.19921266	-1.314	0.2043

F-16 Regression Model

Obs	Dep Var MC	Predict Value	Residual
1	88.3000	88.5848	-0.2848
2	89.0000	89.2978	-0.2978
3	89.0000	88.6951	0.3049
4	88.3000	87.7444	0.5556
5	88.4000	88.2750	0.1250
6	90.1000	90.7423	-0.6423
7	90.8000	91.3189	-0.5189
8	90.2000	90.9629	-0.7629
9	88.9000	89.2203	-0.3203
10	90.9000	90.5780	0.3220
11	91.1000	90.9509	0.1491
12	91.0000	91.2554	-0.2554
13	92.3000	91.4329	0.8671
14	92.7000	91.9964	0.7036
15	93.3000	92.5080	0.7920
16	90.2000	90.9468	-0.7468
17	90.0000	89.7255	0.2745
18	93.0000	92.9593	0.0407
19	94.7000	94.8204	-0.1204
20	93.5000	93.5521	-0.0521
21	92.0000	91.9259	0.0741
22	92.5000	92.3773	0.1227
23	91.2000	91.2144	-0.0144
24	92.0000	92.3154	-0.3154

Sum of Residuals	-622E-16
Sum of Squared Residuals	4.7911
Predicted Resid SS (Press)	8.2625

F-16 Regression Model

Obs	Dep Var MC	Predict Value	Std Err Predict	Lower95% Predict	Upper95% Predict	Residual
1	88.3000	88.5848	0.180	87.4682	89.7014	-0.2848
2	89.0000	89.2978	0.241	88.1316	90.4640	-0.2978
3	89.0000	88.6951	0.293	87.4780	89.9121	0.3049
4	88.3000	87.7444	0.241	86.5788	88.9101	0.5556
5	88.4000	88.2750	0.271	87.0811	89.4689	0.1250
6	90.1000	90.7423	0.156	89.6417	91.8429	-0.6423
7	90.8000	91.3189	0.202	90.1862	92.4515	-0.5189
8	90.2000	90.9629	0.187	89.8414	92.0844	-0.7629
9	88.9000	89.2203	0.272	88.0253	90.4154	-0.3203
10	90.9000	90.5780	0.153	89.4793	91.6768	0.3220
11	91.1000	90.9509	0.103	89.8780	92.0237	0.1491
12	91.0000	91.2554	0.185	90.1354	92.3754	-0.2554
13	92.3000	91.4329	0.130	90.3472	92.5186	0.8671
14	92.7000	91.9964	0.136	90.9076	93.0852	0.7036
15	93.3000	92.5080	0.153	91.4095	93.6064	0.7920
16	90.2000	90.9468	0.345	89.6721	92.2215	-0.7468
17	90.0000	89.7255	0.414	88.3634	91.0876	0.2745
18	93.0000	92.9593	0.361	91.6648	94.2538	0.0407
19	94.7000	94.8204	0.255	93.6413	95.9994	-0.1204
20	93.5000	93.5521	0.203	92.4188	94.6854	-0.0521
21	92.0000	91.9259	0.162	90.8215	93.0303	0.0741
22	92.5000	92.3773	0.189	91.2540	93.5005	0.1227
23	91.2000	91.2144	0.173	90.1024	92.3263	-0.0144
24	92.0000	92.3154	0.183	91.1970	93.4337	-0.3154

Sum of Residuals -622E-16
Sum of Squared Residuals 4.7911
Predicted Resid SS (Press) 8.2625

F-16 99% Prediction Limits

General Linear Models Procedure

Number of observations in data set = 24

Dependent Variable: MC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	70.19389938	17.54847485	69.59	0.0001
Error	19	4.79110062	0.25216319		
Corrected Total	23	74.98500000			
	R-Square	C.V.	Root MSE		MC Mean
	0.936106	0.551974	0.5021585		90.975000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
NMCS	1	66.07790471	66.07790471	262.04	0.0001
HUTE	1	3.14859434	3.14859434	12.49	0.0022
SUTE	1	0.53171067	0.53171067	2.11	0.1628
ABRT	1	0.43568966	0.43568966	1.73	0.2043

Source	DF	Type III SS	Mean Square	F Value	Pr > F
NMCS	1	42.53440453	42.53440453	168.68	0.0001
HUTE	1	0.25593714	0.25593714	1.01	0.3264
SUTE	1	0.54435642	0.54435642	2.16	0.1581
ABRT	1	0.43568966	0.43568966	1.73	0.2043

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	101.7409015	103.77	0.0001	0.98041890
NMCS	-1.5365538	-12.99	0.0001	0.11830918
HUTE	-0.0177430	-1.01	0.3264	0.01761172
SUTE	-0.0869542	-1.47	0.1581	0.05918199
ABRT	-0.2618573	-1.31	0.2043	0.19921266

F-16 Regression Model

Observation	Observed	Predicted Residual	Lower 99% CL Upper 99% CL
1	88.30000000	88.58478863 -0.28478863	87.05855030 90.11102697
2	89.00000000	89.29779884 -0.29779884	87.70370814 90.89188955
3	89.00000000	88.69507777 0.30492223	87.03145233 90.35870321
4	88.30000000	87.74444478 0.55555522	86.15112795 89.33776162
5	88.40000000	88.27497482 0.12502518	86.64304189 89.90690775
6	90.10000000	90.74231007 -0.64231007	89.23791082 92.24670932
7	90.80000000	91.31886525 -0.51886525	89.77059249 92.86713801
8	90.20000000	90.96289769 -0.76289769	89.42995794 92.49583744
9	88.90000000	89.22034784 -0.32034784	87.58588879 90.85380689
10	90.90000000	90.57801700 0.32198300	89.07613474 92.07989926
11	91.10000000	90.95088074 0.14911926	89.48438261 92.41737887
12	91.00000000	91.25543876 -0.25543876	89.72451342 92.78636410
13	92.30000000	91.43286265 0.86713735	89.94881517 92.91691014
14	92.70000000	91.99640413 0.70359587	90.50812532 93.48468294
15	93.30000000	92.50795166 0.79204834	91.00647896 94.00942435
16	90.20000000	90.94682312 -0.74682312	89.20442593 92.68922031
17	90.00000000	89.72549180 0.27450820	87.86364702 91.58733658
18	93.00000000	92.95933656 0.04066344	91.18978464 94.72888849
19	94.70000000	94.82035352 -0.12035352	93.20867251 96.43203453
20	93.50000000	93.55208318 -0.05208318	92.00292749 95.10123887
21	92.00000000	91.82588904 0.07411096	90.41623774 93.43554035
22	92.50000000	92.37725039 0.12274961	90.84182690 93.91267387
23	91.20000000	91.21435092 -0.01435092	89.69437741 92.73432442
24	92.00000000	92.31536082 -0.31536082	90.78671608 93.84400556

F-16 Regression Model

Sum of Residuals	-0.00000000
Sum of Squared Residuals	4.79110062
Sum of Squared Residuals - Error SS	0.00000000
Press Statistic	8.26245707
First Order Autocorrelation	0.25103756
Durbin-Watson D	1.46023897

F/A-18 Correlation Analysis

Correlation Analysis

5 'VAR' Variables: MC NMCS HUTE SUTE ABRT

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
MC	24	70.4250	3.1061	1690	64.8000	76.6000
NMCS	24	11.8042	1.3911	283.3000	9.3000	14.2000
HUTE	24	36.9833	5.0639	887.6000	29.9000	47.5000
SUTE	24	26.6708	3.4254	640.1000	21.7000	35.3000
ABRT	24	4.0992	0.4337	98.3800	3.4000	4.9600

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 24

	MC	NMCS	HUTE	SUTE	ABRT
MC	1.00000 0.0	-0.94083 0.0001	0.41805 0.0421	0.36527 0.0792	-0.11630 0.5884
NMCS	-0.94083 0.0001	1.00000 0.0	-0.50091 0.0127	-0.46595 0.0217	0.15393 0.4727
HUTE	0.41805 0.0421	-0.50091 0.0127	1.00000 0.0	0.88242 0.0001	-0.21058 0.3233
SUTE	0.36527 0.0792	-0.46595 0.0217	0.88242 0.0001	1.00000 0.0	-0.42701 0.0374
ABRT	-0.11630 0.5884	0.15393 0.4727	-0.21058 0.3233	-0.42701 0.0374	1.00000 0.0

F/A-18 Stepwise Regression

Stepwise Procedure for Dependent Variable MC

Step 1 Variable NMCS Entered R-square = 0.88516825 C(p) = 0.27832079

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	196.42326105	196.42326105	169.58	0.0001
Error	22	25.48173895	1.15826086		
Total	23	221.90500000			

Variable	Parameter Estimate	Standard Error	Type III Sum of Squares	F	Prob>F
INTERCEP	95.22233601	1.91682684	2858.36892672	2467.81	0.0001
NMCS	-2.10072737	0.16131562	196.42326105	169.58	0.0001

Bounds on condition number: 1, 1

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable MC

Step	Variable Entered	Number Removed	In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	NMCS		1	0.8852	0.8852	0.2783	169.5846	0.0001

F/A-18 Regression Model

Model: MODEL1

Dependent Variable: MC

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	198.02960	49.50740	39.398	0.0001
Error	19	23.87540	1.25660		
C Total	23	221.90500			
Root MSE	1.12098	R-square	0.8924		
Dep Mean	70.42500	Adj R-sq	0.8698		
C.V.	1.59174				

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > T
INTERCEP	1	98.987526	5.09777082	19.418	0.0001
NMCS	1	-2.187920	0.19456550	-11.245	0.0001
HUTE	1	0.028445	0.10903122	0.261	0.7970
SUTE	1	-0.125657	0.17044287	-0.737	0.4700
ABRT	1	-0.106498	0.64778203	-0.164	0.8711

F/A-18 Regression Model

Obs	Dep Var MC	Predict Value	Residual
1	74.7000	75.7708	-1.0708
2	71.4000	71.6606	-0.2606
3	74.3000	75.0829	-0.7829
4	76.6000	75.2267	1.3733
5	74.1000	73.2035	0.8965
6	73.8000	72.2003	1.5997
7	72.1000	71.8881	0.2119
8	71.5000	71.4106	0.0894
9	72.8000	73.1931	-0.3931
10	64.8000	67.2007	-2.4007
11	69.3000	69.0344	0.2656
12	68.5000	70.2033	-1.7033
13	68.4000	68.2792	0.1208
14	66.1000	65.1721	0.9279
15	66.7000	67.9118	-1.2118
16	67.6000	66.7128	0.8872
17	67.3000	66.0343	1.2657
18	67.8000	67.5727	0.2273
19	72.0000	71.5138	0.4862
20	71.2000	71.6418	-0.4418
21	69.0000	69.5412	-0.5412
22	71.2000	71.2302	-0.0302
23	67.3000	68.1131	-0.8131
24	71.7000	70.4018	1.2982

Sum of Residuals	0
Sum of Squared Residuals	23.8754
Predicted Resid SS (Press)	38.3844

F/A-18 Regression Model

Obs	Dep Var MC	Predict Value	Std Err Predict	Lower95% Predict	Upper95% Predict	Residual
1	74.7000	75.7708	0.673	73.0339	78.5077	-1.0708
2	71.4000	71.6606	0.652	68.9463	74.3748	-0.2606
3	74.3000	75.0829	0.518	72.4987	77.6671	-0.7829
4	76.6000	75.2267	0.507	72.6517	77.8016	1.3733
5	74.1000	73.2035	0.433	70.6981	75.7188	0.8965
6	73.8000	72.2003	0.588	69.5505	74.8501	1.5997
7	72.1000	71.8881	0.408	69.3912	74.3851	0.2119
8	71.5000	71.4106	0.490	68.8498	73.9714	0.0894
9	72.8000	73.1931	0.505	70.6195	75.7666	-0.3931
10	64.8000	67.2007	0.562	64.5763	69.8252	-2.4007
11	69.3000	69.0344	0.403	66.5412	71.5276	0.2656
12	68.5000	70.2033	0.293	67.7781	72.6284	-1.7033
13	66.4000	68.2792	0.322	65.8382	70.7202	0.1208
14	66.1000	65.1721	0.558	62.5510	67.7932	0.9279
15	66.7000	67.9118	0.459	65.3769	70.4468	-1.2118
16	67.6000	66.7128	0.475	64.1644	69.2613	0.8872
17	67.3000	66.0343	0.447	63.5087	68.5599	1.2657
18	67.8000	67.5727	0.427	65.0623	70.0831	0.2273
19	72.0000	71.5138	0.678	68.7720	74.2557	0.4862
20	71.2000	71.6418	0.872	68.6691	74.6144	-0.4418
21	69.0000	69.5412	0.440	67.0210	72.0615	-0.5412
22	71.2000	71.2302	0.451	68.7010	73.7594	-0.0302
23	67.3000	68.1131	0.321	65.6725	70.5536	-0.8131
24	71.7000	70.4018	0.408	67.9050	72.8987	1.2982

Sum of Residuals 0
Sum of Squared Residuals 23.8754
Predicted Resid SS (Press) 39.3844

F/A-18 99% Prediction Limits

General Linear Models Procedure

Number of observations in data set = 24

Dependent Variable: MC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	198.02959901	49.50739975	39.40	0.0001
Error	19	23.87540099	1.25660005		
Corrected Total	23	221.90500000			

R-Square	C.V.	Root MSE	MC Mean
0.892407	1.591738	1.1209817	70.425000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
NMCS	1	196.42326105	196.42326105	156.31	0.0001
HUTE	1	0.83887071	0.83887071	0.67	0.4240
SUTE	1	0.73350276	0.73350276	0.58	0.4542
ABRT	1	0.03396450	0.03396450	0.03	0.8711

Source	DF	Type III SS	Mean Square	F Value	Pr > F
NMCS	1	158.90164843	158.90164843	126.45	0.0001
HUTE	1	0.08552620	0.08552620	0.07	0.7970
SUTE	1	0.68298750	0.68298750	0.54	0.4700
ABRT	1	0.03396450	0.03396450	0.03	0.8711

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	98.98752585	19.42	0.0001	5.09777082
NMCS	-2.18792027	-11.25	0.0001	0.19456550
HUTE	0.02844474	0.26	0.7970	0.10903122
SUTE	-0.12565700	-0.74	0.4700	0.17044287
ABRT	-0.10549837	-0.16	0.8711	0.64778203

F/A-18 Regression Model

Observation	Observed	Predicted Residual	Lower 99% CL Upper 99% CL
1	74.70000000	75.77081971 -1.07081971	72.02973025 79.51190918
2	71.40000000	71.66058379 -0.26058379	67.95045701 75.37071057
3	74.30000000	75.08290063 -0.78290063	71.55054134 78.61525992
4	76.60000000	75.22667751 1.37332249	71.70693596 78.74641906
5	74.10000000	73.20345770 0.89654230	69.76517572 76.64173968
6	73.80000000	72.20032866 1.59967134	68.57831049 75.82234684
7	72.10000000	71.88814416 0.21185584	68.47509559 75.30119272
8	71.50000000	71.41064533 0.08935467	67.91026721 74.91102346
9	72.80000000	73.19305536 -0.39305536	69.67527530 76.71083543
10	64.80000000	67.20074933 -2.40074933	63.61339378 70.78810488
11	69.30000000	69.03440363 0.26559637	65.62642252 72.44238474
12	68.50000000	70.20327445 -1.70327445	66.88834679 73.51820211
13	68.40000000	68.27919336 0.12080664	64.94253375 71.61585297
14	66.10000000	65.17209017 0.92790983	61.58930973 68.75487060
15	66.70000000	67.91184970 -1.21184970	64.44673703 71.37696236
16	67.60000000	66.71284754 0.88715246	63.22937883 70.19631626
17	67.30000000	66.03431043 1.26568957	62.58206046 69.48656040
18	67.80000000	67.57270747 0.22729253	64.14119069 71.00422425
19	72.00000000	71.51383616 0.48616384	67.76596341 75.26170890
20	71.20000000	71.64175296 -0.44175296	67.57845752 75.70504841
21	69.00000000	69.54121693 -0.54121693	66.09627487 72.98615898
22	71.20000000	71.23022141 -0.03022141	67.77304162 74.68740121
23	67.30000000	68.11308951 -0.81308951	64.77708675 71.44909227
24	71.70000000	70.40184410 1.29815590	66.98888515 73.81480306

F/A-18 Regression Model

Sum of Residuals	-0.00000000
Sum of Squared Residuals	23.87540099
Sum of Squared Residuals - Error SS	-0.00000000
Press Statistic	39.38444829
First Order Autocorrelation	0.02040319
Durbin-Watson D	1.84058353

Appendix E: Double Cross-Validation

F-14

<u>OBS</u>	<u>ACTUAL MC</u>	<u>ODD PRED</u>	<u>ODD FILE DIFFERENCE</u>	<u>EVEN PRED</u>	<u>EVEN FILE DIFFERENCE</u>
1	70.4	68.2926	2.1074	*	
2	66.3	*		67.495	-1.195
3	66.2	62.6733	3.5267	*	
4	59.5	*		65.0976	-5.5976
5	70.0	68.9869	1.0131	*	
6	66.2	*		62.5182	3.6818
7	68.5	70.9786	-2.4786	*	
8	68.0	*		66.3131	1.6869
9	69.4	70.7467	-1.3467	*	
10	64.3	*		64.6066	-0.3066
11	63.9	61.7938	2.1062	*	
12	58.7	*		61.8335	-3.1335
13	56.9	60.4465	-3.5465	*	
14	60.4	*		63.494	-3.094
15	61.6	62.1241	-0.5241	*	
16	55.2	*		55.1403	0.0597
17	58.7	58.2553	0.4447	*	
18	62.5	*		58.1189	4.3811
19	60.8	61.2427	-0.4427	*	
20	59.1	*		54.5059	4.5941
21	63.7	61.8559	1.8441	*	
22	62.5	*		62.7454	-0.2454
23	60.8	60.9243	-0.1243	*	
24	62.5	*		62.1022	0.3978

CONFIDENCE INTERVALS FOR ODD FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
0.2149	2.0540	1.5069	-1.0770	95%
		2.0263	-1.5964	99%

CONFIDENCE INTERVALS FOR EVEN FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
0.1024	3.1485	2.0829	-1.8780	95%
		2.8791	-2.6742	99%

F-15

<u>OBS</u>	<u>ACTUAL</u> <u>MC</u>	<u>ODD</u> <u>PRED</u>	<u>ODD FILE</u> <u>DIFFERENCE</u>	<u>EVEN</u> <u>PRED</u>	<u>EVEN FILE</u> <u>DIFFERENCE</u>
1	84.2	85.2549	-1.0549	*	*
2	83.0	*	*	82.4627	0.5373
3	83.8	84.4918	-0.6918	*	*
4	84.5	*	*	84.1599	0.3401
5	85.5	84.9613	0.5387	*	*
6	85.8	*	*	84.1027	1.6973
7	86.2	85.6611	0.5389	*	*
8	86.0	*	*	84.493	1.507
9	84.2	86.1249	-1.9249	*	*
10	84.4	*	*	83.9312	0.4688
11	81.7	85.1612	-3.4612	*	*
12	84.2	*	*	84.7574	-0.5574
13	82.0	84.1861	-2.1861	*	*
14	82.3	*	*	83.9513	-1.6513
15	85.5	85.4496	0.0504	*	*
16	83.9	*	*	82.5435	1.3565
17	83.9	84.1697	-0.2697	*	*
18	87.2	*	*	85.6332	1.5668
19	84.6	84.9944	-0.3944	*	*
20	85.5	*	*	83.8054	1.6946
21	84.1	84.3669	-0.2669	*	*
22	84.8	*	*	83.0786	1.7214
23	82.8	83.8857	-1.0857	*	*
24	85.8	*	*	84.3073	1.4927

CONFIDENCE INTERVALS FOR ODD FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER</u> <u>LIMIT</u>	<u>LOWER</u> <u>LIMIT</u>	<u>CONF</u> <u>INT</u>
-0.4253	0.9273	0.1580	-1.0086	95%
		0.3925	-1.2431	99%

CONFIDENCE INTERVALS FOR EVEN FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER</u> <u>LIMIT</u>	<u>LOWER</u> <u>LIMIT</u>	<u>CONF</u> <u>INT</u>
0.4239	0.8561	0.9624	-0.1146	95%
		0.3925	-1.2431	99%

F-16

<u>OBS</u>	<u>ACTUAL MC</u>	<u>ODD PRED</u>	<u>ODD FILE DIFFERENCE</u>	<u>EVEN PRED</u>	<u>EVEN FILE DIFFERENCE</u>
1	88.3	88.5734	-0.2734	*	*
2	89.0	*	*	89.5181	-0.5181
3	89.0	88.476	0.524	*	*
4	88.3	*	*	87.4831	0.8169
5	88.4	88.3951	0.0049	*	*
6	90.1	*	*	90.6865	-0.5865
7	90.8	91.34	-0.54	*	*
8	90.2	*	*	90.7236	-0.5236
9	88.9	89.4861	-0.5861	*	*
10	90.9	*	*	90.3787	0.5213
11	91.1	90.8427	0.2573	*	*
12	91.0	*	*	91.776	-0.776
13	92.3	91.2649	1.0351	*	*
14	92.7	*	*	92.1784	0.5216
15	93.3	92.2902	1.0098	*	*
16	90.2	*	*	92.0811	-1.8811
17	90.0	89.2497	0.7503	*	*
18	93.0	*	*	93.6507	-0.6507
19	94.7	94.7034	-0.0034	*	*
20	93.5	*	*	93.8178	-0.3178
21	92.0	91.9543	0.0457	*	*
22	92.5	*	*	92.3929	0.1071
23	91.2	90.9897	0.2103	*	*
24	92.0	*	*	92.6576	-0.6576

CONFIDENCE INTERVALS FOR ODD FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
0.1014	0.3903	0.1580	-1.0086	95%
		0.3925	-1.2431	99%

CONFIDENCE INTERVALS FOR EVEN FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
-0.1644	0.5340	0.9624	-0.1146	95%
		0.3925	-1.2431	99%

F/A-18

<u>OBS</u>	<u>ACTUAL MC</u>	<u>ODD PRED</u>	<u>ODD FILE DIFFERENCE</u>	<u>EVEN PRED</u>	<u>EVEN FILE DIFFERENCE</u>
1	74.7	77.418	-2.718	*	*
2	71.4	*	*	72.0162	-0.6162
3	74.3	75.7832	-1.4832	*	*
4	76.6	*	*	75.6649	0.9351
5	74.1	73.6982	0.4018	*	*
6	73.8	*	*	72.3226	1.4774
7	72.1	72.0722	0.0278	*	*
8	71.5	*	*	70.7236	0.7764
9	72.8	73.5342	-0.7342	*	*
10	64.8	*	*	68.2074	-3.4074
11	69.3	68.6436	0.6564	*	*
12	68.5	*	*	69.8569	-1.3569
13	68.4	68.2864	0.1136	*	*
14	66.1	*	*	64.818	1.282
15	66.7	68.3936	-1.6936	*	*
16	67.6	*	*	66.8949	0.7051
17	67.3	65.5567	1.7433	*	*
18	67.8	*	*	67.5691	0.2309
19	72.0	72.1455	-0.1455	*	*
20	71.2	*	*	73.256	-2.056
21	69.0	69.8227	-0.8227	*	*
22	71.2	*	*	70.5297	0.6703
23	67.3	68.1846	-0.8846	*	*
24	71.7	*	*	69.6135	2.0865

CONFIDENCE INTERVALS FOR ODD FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
-0.2308	0.8557	0.1580	-1.0086	95%
		0.3925	-1.2431	99%

CONFIDENCE INTERVALS FOR EVEN FILE MODEL

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
0.0303	1.1169	0.9624	-0.1146	95%
		0.3925	-1.2431	99%

Appendix F: Exchange of Independent Variables

F-15 to F-14

<u>OBS</u>	<u>F-15 PRED MC</u>	<u>F-14 PRED MC</u>	<u>F-15 TO F-14 DIFFERENCE</u>
1	84.7992	68.2953	16.5039
2	83.0124	64.9053	18.1071
3	84.0524	62.9962	21.0562
4	84.4440	61.5397	22.9043
5	84.5213	68.9056	15.6157
6	84.6116	65.3996	19.2120
7	85.2132	71.1018	14.1114
8	84.8746	67.6291	17.2455
9	85.4941	70.7106	14.7835
10	84.4196	64.7801	19.6395
11	84.7905	62.1693	22.6212
12	85.2387	60.4176	24.8211
13	83.7992	60.4359	23.3633
14	84.3865	61.4761	22.9104
15	84.9756	62.4116	22.5640
16	83.0492	54.8244	28.2248
17	83.5997	58.6457	24.9540
18	85.8793	62.2775	23.6018
19	84.6610	61.3394	23.3216
20	84.3906	59.0529	25.3377
21	84.0963	61.8617	22.2346
22	83.6624	60.5816	23.0808
23	83.3180	61.1354	22.1826
24	84.6103	63.2077	21.4026

CONFIDENCE INTERVALS FOR COMPARISON OF F-15 TO F-14 PRED MC RATES

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
21.2417	3.6126	22.7637	19.7196	95%
		23.3042	19.1791	99%

F-16 to F/A-18

<u>OBS</u>	<u>F-16 PRED MC</u>	<u>F/A-18 PRED MC</u>	<u>F-16 TO F/A-18 DIFFERENCE</u>
1	88.5848	75.7708	12.8140
2	89.2978	71.6606	17.6372
3	88.6951	75.0829	13.6122
4	87.7444	75.2267	12.5177
5	88.2750	73.2035	15.0715
6	90.7423	72.2003	18.5420
7	91.3189	71.8881	19.4308
8	90.9629	71.4106	19.5523
9	89.2203	73.1931	16.0272
10	90.5780	67.2007	23.3773
11	90.9509	69.0344	21.9165
12	91.2554	70.2033	21.0521
13	91.4329	68.2792	23.1537
14	91.9964	65.1721	26.8243
15	92.5080	67.9118	24.5962
16	90.9468	66.7128	24.2340
17	89.7255	66.0343	23.6912
18	92.9593	67.5727	25.3866
19	94.8204	71.5138	23.3066
20	93.5521	71.6418	21.9103
21	91.9259	69.5412	22.3847
22	92.3773	71.2302	21.1471
23	91.2144	68.1131	23.1013
24	92.3154	70.4018	21.9136

CONFIDENCE INTERVALS FOR COMPARISON OF F-16 TO F/A-18 PRED
MC RATES

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
20.5500	4.0579	22.2597	18.8404	95%
		22.8668	18.2332	99%

Appendix G: Cross Model Comparison

F-15 and F-14 COMPARISON

<u>OBS</u>	<u>F-15 PRED(AF)</u>	<u>F-15 PRED(USN)</u>	<u>F-14 PRED(USN)</u>	<u>F-14 PRED(AF)</u>	<u>USN DIFFERENCE</u>	<u>USAF DIFFERENCE</u>
1	84.7992	77.5226	68.2953	79.9646	7.2765	-11.6693
2	83.0124	72.9103	64.9053	78.2781	10.1020	-13.3728
3	84.0524	72.3265	62.9962	79.0025	11.7258	-16.0063
4	84.4440	75.5303	61.5397	77.6195	8.9136	-16.0799
5	84.5213	75.9718	68.9056	80.2781	8.5494	-11.3725
6	84.6116	78.2644	65.3996	79.8191	6.3471	-14.4196
7	85.2132	79.8350	71.1018	79.8766	5.3781	-8.7748
8	84.8746	77.6249	67.6291	80.1707	7.2496	-12.5417
9	85.4941	78.2551	70.7106	80.2635	7.2389	-9.5529
10	84.4196	76.9324	64.7801	79.2911	7.4871	-14.5111
11	84.7905	76.5812	62.1693	79.5394	8.2092	-17.3701
12	85.2387	77.5226	60.4176	79.0256	7.7160	-18.6080
13	83.7992	74.3394	60.4359	79.4120	9.4597	-18.9761
14	84.3865	75.3096	61.4761	78.6227	9.0768	-17.1467
15	84.9756	74.4681	62.4116	80.1822	10.5074	-17.7707
16	83.0492	71.8552	54.8244	78.2685	11.1939	-23.4442
17	83.5997	70.3649	58.6457	79.1949	13.2347	-20.5492
18	85.8793	76.3129	62.2775	80.9385	9.5663	-18.6611
19	84.6610	76.5022	61.3394	77.2298	8.1587	-15.8905
20	84.3906	77.5599	59.0529	77.3267	6.8306	-18.2739
21	84.0963	76.7336	61.8617	78.5837	7.3626	-16.722
22	83.6624	75.9262	60.5816	78.4833	7.7361	-17.9018
23	83.3180	71.8523	61.1354	78.7674	11.4656	-17.632
24	84.6103	72.1537	63.2077	79.7109	12.4565	-16.5033

CONFIDENCE INTERVALS FOR F-15 PRED (USAF) TO F-15 PRED (USN) MC RATES

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
8.8851	2.0395	9.7444	8.0259	95%
		10.0496	7.7207	99%

CONFIDENCE INTERVALS FOR F-14 PRED (USN) TO F-14 PRED (USAF) MC RATES

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
-15.9896	3.4574	-14.5330	-17.4462	95%
		-14.0157	-17.9636	99%

F-16 and F/A-18 COMPARISON

<u>OBS</u>	<u>F-16 PRED(AF)</u>	<u>F-16 PRED(USN)</u>	<u>F/A-18 PRED(USN)</u>	<u>F/A-18 PRED(AF)</u>	<u>USN DIFFERENCE</u>	<u>USAF DIFFERENCE</u>
1	88.5848	83.0068	75.7708	87.9390	5.5779	-12.1683
2	89.2978	84.0572	71.6606	86.2502	5.2405	-14.5897
3	88.6951	83.0935	75.0829	87.4986	5.6015	-12.4158
4	87.7444	81.6655	75.2267	88.0489	6.0788	-12.8223
5	88.2750	82.2396	73.2035	86.3872	6.0353	-13.1837
6	90.7423	86.0540	72.2003	85.3104	4.6882	-13.1101
7	91.3189	86.7083	71.8881	85.8014	4.6105	-13.9134
8	90.9629	86.0296	71.4106	85.2424	4.9332	-13.8318
9	89.2203	83.6027	73.1931	86.9333	5.6175	-13.7403
10	90.5780	85.6586	67.2007	82.0938	4.9193	-14.8931
11	90.9509	86.3232	69.0344	83.5222	4.6276	-14.4878
12	91.2554	86.6522	70.2033	84.0692	4.6031	-13.8659
13	91.4329	87.0907	68.2792	82.6605	4.3421	-14.3813
14	91.9964	87.7491	65.1721	80.3923	4.2472	-15.2202
15	92.5080	88.5035	67.9118	81.7872	4.0044	-13.8755
16	90.9468	87.5643	66.7128	81.9257	3.3824	-15.2130
17	89.7255	86.4408	66.0343	80.8229	3.2846	-14.7886
18	92.9593	88.6379	67.5727	81.5243	4.3213	-13.9516
19	94.8204	91.2347	71.5138	84.3909	3.5856	-12.8771
20	93.5521	89.6813	71.6418	84.8903	3.8707	-13.2485
21	91.9259	87.3281	69.5412	82.9625	4.5977	-13.4213
22	92.3773	88.1276	71.2302	84.0898	4.2496	-12.8597
23	91.2144	86.7706	68.1131	82.3597	4.4437	-14.2467
24	92.3154	87.6723	70.4018	83.7212	4.6430	-13.3194

CONFIDENCE INTERVALS FOR F-16 PRED (USAF) TO F-16 PRED (USN) MC RATES

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
4.6461	0.7624	4.9673	4.3249	95%
		5.0814	4.2108	99%

CONFIDENCE INTERVALS FOR F/A-18 PRED (USN) TO F/A-18 PRED (USAF) MC RATE

<u>MEAN</u>	<u>STD DEV</u>	<u>UPPER LIMIT</u>	<u>LOWER LIMIT</u>	<u>CONF INT</u>
-13.7677	0.8508	-13.4093	-14.1262	95%
		-13.2819	-14.2535	99%

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