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THESIS

**OPTIMIZING MAINTENANCE MANPOWER FOR
USMC F/A-18 SQUADRONS**

by

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June 2016

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OPTIMIZING MAINTENANCE MANPOWER FOR USMC F/A-18 SQUADRONS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

United States Marine Corps F/A-18 squadrons face increasing maintenance requirements to keep their aging aircraft operationally ready. Each squadron maintenance department has six production work centers (WCs) that specialize in different maintenance activities. Each Marine in one of the six production WCs belongs to one of three categories of experience level, with some maintenance actions requiring certification by a member of the most experienced category before an aircraft can fly. This thesis formulates the Manpower Validation Planner (MVP), an integer linear program that daily assigns tasks to available Marines from each WC and experience level to a squadron's maintenance actions, with the requirement to keep a standard number of aircraft operationally ready. We demonstrate the MVP using two years of daily maintenance and manning data from five F/A-18 squadrons to calculate the number of used, unused, and deficit hours of work. Our baseline analysis shows the majority of WCs in an F/A-18 maintenance department have sufficient manpower available, but that two WCs are overtasked. Additional analysis shows the impossibility of keeping the required number of aircraft operationally ready given the time available to fix aircraft and evaluates mitigation strategies.

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LIST OF ACRONYMS AND ABBREVIATIONS

AMO	Aircraft Maintenance Officer
AMSRR	Aviation Management Supply and Readiness Reporting
ASR	Authorized Strength Report
BUNO	Bureau Number
CDI	Collateral Duty Inspector
CDQAR	Collateral Duty Quality Assurance Representative
CMC	Commandant of the Marine Corps
CNA	Center for Naval Analyses
CNAF	Commander, Naval Air Forces
CO	Commanding Officer
DCA	Deputy Commandant for Aviation
DECKPLATE	Decision Knowledge Programming for Logistics Analysis and Technical Evaluation
EMT	Elapsed Maintenance Time
F/A	Fighter/Attack
FAP	Fleet Assistance Program
FCF	Functional Check Flight
FOD	Foreign Object Damage
FMC	Full Mission Capable
FRC	Fleet Readiness Center
GAMS	Generic Algebraic Modeling System
I-Level	Intermediate Level
IR	In Reporting
ISR	In-Service Repair
JSF	Joint Strike Fighter
MACCRAT	Marine Aviation Commanders' Current Readiness Assessment Tool
MAF	Maintenance Action Form
MAG	Marine Aircraft Group
MAGTF	Marine Air-Ground Task Force

MALS	Marine Aviation Logistics Squadron
MC	Mission Capable
MCAS	Marine Corps Air Station
MCC	Maintenance Core Competency
MCO	Marine Corps Order
MESM	Mission Essential Subsystem Matrix
MOS	Military Occupational Specialty
MVP	Manpower Validation Planner
NAVAIR	Naval Air Systems Command
NMC	Non-Mission Capable
NMCS	Non-Mission Capable Supply
O-Level	Organization Level
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OOD	Out-Of Reporting
PMC	Partial Mission Capable
PMI	Planned Maintenance Inspection
RBA	Ready Basic Aircraft
T&R	Training and Readiness
TACAIR	Tactical Aircraft
TFSMS	Total Force Structure Management System
T/O	Table of Organization
UDP	Unit Deployment Program
USMC	United States Marine Corps
VMFA	Fixed Wing Marine Fighter Attack
VMFA(AW)	Fixed Wing Marine All Weather Fighter Attack
WC	Work Center
WSO	Weapons Systems Officer
WTI	Weapons and Tactics Instructor

EXECUTIVE SUMMARY

Across United States Marine Corps (USMC) aviation, squadrons are short of the requisite number of Ready Basic Aircraft (RBA) to sustain required levels of aircrew readiness. This is especially true in the F/A-18 community, which has seen a reduction in readiness as a result of rising numbers of aircraft in depot-level maintenance, flight hour usage beyond planned levels due to 15 years of combat operations, and continual delays in the delivery of the F-35 Joint Strike Fighter (JSF). In order to be ready to fight tonight, the aircraft on the flight line need to be kept “up” and ready to fly.

USMC F/A-18 squadrons face increasing maintenance requirements to keep their aging aircraft operationally ready. Each squadron has 13 maintenance work centers (WCs) that specialize in different maintenance activities. Of that, six are considered production WCs. Each Marine in one of the six production WCs belongs to one of three categories of experience level, with some maintenance actions requiring certification by a member of the most experienced level before an aircraft can fly.

This thesis formulates the Manpower Validation Planner (MVP), an integer linear program that daily assigns tasks to available Marines from each WC and each experience level to a squadron’s maintenance actions, with the requirement to keep a standard number of aircraft operationally ready. We demonstrate the MVP using two years of daily maintenance and manning data from five F/A-18 squadrons to calculate the number of used, unused, and deficit hours of work.

Our baseline analysis shows that the majority of WCs in an F/A-18 maintenance department have sufficient manpower available but two WCs are overtasked. Excursions investigate the impact of changes to manpower. For example, increasing the Seat Shop WC by one Marine helps lessen overtasking but does not eliminate it completely.

Due to an increase in the maintenance requirements of an aging F/A-18, additional analysis shows the impossibility of keeping the standard number of aircraft operationally ready every day given the time available to fix aircraft. Squadrons normally plan for a maintenance day at least once a month when no flight operations occur.

Planning more maintenance days into a squadron's calendar improves the time available but MVP finds two maintenance days each month is still insufficient to meet the required hours to fix enough aircraft every day to maintain a standard number of aircraft operationally ready.

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I. INTRODUCTION

United States Marine Corps Fighter/Attack (F/A) squadrons face increasing maintenance requirements to keep their aging aircraft operationally ready. Each squadron has 13 maintenance work centers (WCs), of which six are considered production WCs that specialize in different maintenance activities. Each Marine in one of the six production WCs belongs to one of three categories of experience level, with some maintenance actions requiring certification by a member of the most experienced level before an aircraft can fly. This thesis formulates, implements, and demonstrates the MVP, an integer linear program that daily assigns tasks to available Marines from each WC and each experience level to a squadron's maintenance actions, with the goal of keeping as many aircraft as possible operationally ready.

A. THESIS ORGANIZATION

The remainder of this chapter discusses the framework of Organizational Level (O-Level) Maintenance, readiness as it pertains to F/A-18 Hornets in the USMC, manning, and the thesis problem. Chapter II presents research related to this thesis. Chapter III introduces a representative MVP integer linear program. Chapter IV summarizes the MVP data assumptions, the MVP implementation, and results. Chapter V provides recommendations and suggested further research.

B. USMC F/A-18 SQUADRON STRUCTURE

The F/A-18 Hornet (Figure 1) first entered operational service for the USMC in January 1983 (Flying Leathernecks 2016) and over the years there have been four model variants produced: A, B, C, and D. The A and C models have a single seat and the B and D models have two seats. There have been modifications to all of them, with all but the A model retaining its original designation. After undergoing two significant modifications, the A model is now the A++.



Figure 1. Two F/A-18Ds from VMFA(AW)-121 Conduct Training over the California Desert. Source: Carlson 2006.

There are currently 13 USMC Hornet squadrons, including active, reserve, and training squadrons, flying all models of the F/A-18. The active and reserve squadrons are either Fixed Wing Marine Fighter Attack (VMFA) or Fixed Wing Marine All Weather Fighter Attack (VMFA(AW)), the former flies the single seat variant and the latter the two seat variant.

The mission of a VMFA squadron is to “Support the MAGTF [Marine Air-Ground Task Force] Commander by destroying surface targets and enemy aircraft, day or night under all weather conditions during expeditionary, joint or combined operations” (Commandant of the Marine Corps [CMC] 2012a). The mission of a VMFA(AW) squadron is to “Support the MAGTF Commander by supporting arms coordination, conducting multi-sensor imagery reconnaissance, and destroying surface targets and enemy aircraft, day or night under all weather conditions during expeditionary, joint or combined operations” (CMC 2012a). The additional missions for VMFA(AW) squadrons

require an additional crewmember, a Weapons Systems Officer (WSO), and an increase in the capabilities of the aircraft.

Each USMC Hornet squadron, with the exception of the training squadron, is ideally composed of 12 F/A-18s. Manning is slightly different between them, a VMFA squadron has a Table of Organization (T/O) describing the required rank and Military Occupational Specialty (MOS) for a squadron consisting of 23 officers and 167 enlisted Marines and a VMFA(AW) squadron has a T/O structure of 42 officers and 164 enlisted Marines (USMC 2015). The enlisted manning is very similar between the two types of squadrons but the officer structure is very different due to the addition of 19 WSOs to a VMFA(AW) squadron (USMC 2015). Each squadron has seven departments, such as administration and operations, but the maintenance department has roughly 140 to 150 assigned Marines (USMC 2015).

C. USMC F/A-18 SQUADRON MAINTENANCE

There are three levels of F/A-18 maintenance repairs: O-Level, completed by Marines in a squadron; Intermediate Level (I-Level), completed by Marines in a Marine Aviation Logistics Squadron (MALS); and depot-level, completed by civilian artisans either on-site or at a Fleet Readiness Center (FRC). This thesis only considers O-Level maintainers. There are 13 O-Level WCs in an F/A-18 squadron with the six production WCs being the focus of this thesis. The production WCs are Airframes Shop (WC 120 and MOS 6257), Communications and Avionics Shop (WC 210 and MOS 6317), Electric Shop (WC 220 and MOS 6337), Ordnance Shop (WC 230 and MOS 6531), Powerline Shop (WC 310 and MOS 6217), and Seat Shop (WC 13B and MOS 6287).

When an aircraft requires any type of maintenance, Marines generate a Maintenance Action Form (MAF). The MAF contains a description of the problem and the applicable work center. As work on the MAF begins, workers of the appropriate skill level are assigned and parts are ordered if necessary. The MAF is considered “signed-off” when a maintainer of the appropriate skill level inspects the work to ensure the corrective action complies with specifications.

Each Marine in a production WC belongs to one of three maintenance qualification categories: mechanic/technician; Collateral Duty Inspector (CDI); or the highest level of qualification, Collateral Duty Quality Assurance Representative (CDQAR). Each maintenance action or repair, documented on a MAF, typically requires a mixture of skill levels from each MOS, beginning with the mechanic/technician, then the CDI, and the CDQAR (Figure 2). Only the CDIs and CDQARs have the authority to “sign-off” a MAF signifying the repair is complete. CDIs have specific maintenance actions they “sign-off” for their WC, whereas CDQARs have authority to “sign-off” all maintenance actions for their WC.



Figure 2. A Powerline WC CDQAR Conducting Maintenance on an F/A-18 Engine. Source: Marines 2013.

The amount of maintenance to be conducted in an F/A-18 squadron varies on a daily basis. There are two categories of maintenance: scheduled and unscheduled. Scheduled maintenance is time-based maintenance that is either on a calendar-day cycle

or flight-hour usage cycle. The calendar days, with cycles that can vary from 7 to 728 days, are easier to plan for than flight hour based, which have cycles that can vary from 10 to 600 hours. The unscheduled maintenance is random; while there may be some level of intuition that something is about to break, it is difficult to know exactly what part will break or when it will occur.

There is an additional category of scheduled maintenance dictated by Naval Air Systems Command (NAVAIR) for the entire inventory of F/A-18s that requires aircraft be flown to an FRC for Planned Maintenance Induction (PMI). There are two sequential PMI events, PMI-1, which is scheduled for 240–290 work days, and PMI-2, which follows PMI-1 and is scheduled for 42–56 work days, both depending on FRC location (NAVAIR 2016b). Recently both PMIs have experienced significant delays and the most recent completion time for PMI-1 is between 357–487 work days and 61–63 work days for PMI-2, both depending on FRC location (NAVAIR 2016b). The arrival date for an aircraft is almost unchangeable while the return date changes frequently, potentially twice as long as in the original timeline.

There is also an additional category of unscheduled maintenance called an In-Service Repair (ISR). An ISR, such as the repair for the fuselage skin crack shown in Figure 3, is a depot level repair where artisans travel to an aircraft's location to complete the repair. Generally these repairs take only days to complete but there can be lengthy delays before work commences. Almost every ISR requires a specific engineering instruction prior to work commencing and there is generally a backlog of engineering requests. Additionally, there are a limited number of artisans to service all USMC aircraft.



Figure 3. Fuselage Skin Crack on F/A-18D requiring ISR.

D. USMC F/A-18 AIRCRAFT MISSION AND REPORTING STATUS

Daily, each aircraft is in one of two reporting status conditions: In-Reporting (IR) status and Out-Of Reporting (OOR) status. O-Level maintainers only work on IR aircraft. An aircraft in OOR status has a serious maintenance issue that requires repair by a depot level artisan.

Each IR aircraft is in one of three mission level statuses: Full Mission Capable (FMC); Partial Mission Capable (PMC); and Non-Mission Capable (NMC). A FMC aircraft can fly and there are no outstanding MAFs on the aircraft (in other words, all systems are fully functional). A PMC aircraft can fly but there is at least one open PMC MAF (pending “sign-off”) on the aircraft signifying that not all systems are fully functional. For the purpose of this thesis, we use Mission Capable (MC) for an aircraft

that is either FMC or PMC (a MC aircraft is considered “up,” and can fly). Additionally, we assume a MC aircraft is a RBA. NMC aircraft either have at least one open NMC MAF that makes the aircraft non-flyable or has accumulated more than ten open PMC MAFs. In both cases, the aircraft is NMC, or “down,” and unable to fly.

E. MAINTENANCE DAY

In each month there is rarely sufficient time to keep up with maintenance requirements without taking a day off from flight operations. Squadrons normally plan for a maintenance day at least once a month when no flight operations occur. Depending on the aircraft health in the squadron, the squadron may schedule more than one maintenance day per month.

In addition to scheduling a maintenance day, a squadron can also work overtime based on a recommendation from the Aircraft Maintenance Officer (AMO) and concurrence from the Commanding Officer (CO). There are a maximum number of days that overtime can be worked per month based on an unwritten rule for how many days it is beneficial for a squadron to do so. Working overtime during the week is referred to as 12 on/12 off. The maintenance department is always split into two crews, day crew and night crew, with the exception being single crew operations when manning levels are lower, such as block leave periods. During 12 on/12 off operations, day crew works from 0700–1900 and night crew works from 1900–0700. Aside from additional hours to work on aircraft, there are additional benefits to around the clock maintenance such as face to face information exchanges. This allows the oncoming crew to have a complete picture of what the off-going crew has been working on and where they need to concentrate their efforts.

F. USMC F/A-18 SQUADRON FLIGHT OPERATIONS

Assuming a squadron has 12 aircraft IR, there are different requirements for the daily number of MC aircraft depending on the day’s flight schedule. Aircraft almost always launch as a section (two aircraft), the major exception being a Functional Check Flight (FCF), which are single ship flights to check airworthiness after completion of specific maintenance actions. The rule of thumb is for every two aircraft on the schedule

to fly, one additional aircraft is ready as a back-up. A typical flight schedule consists of three separate launches with six aircraft in each launch for a total of 18 aircraft sorties (flights) per day. Using the rule of thumb, this equates to having nine RBA available for each launch.

The squadron CO makes a decision daily how best to keep the squadron sustainable from both a tactical and personnel readiness standpoint. The CO weighs the factors and must decide whether the best course of action is to work longer in a day, series of days, or even on the weekend, in order to have more RBA. The counter to working longer is the negative impact it will have on the morale and overall readiness of the squadron. There are times it makes sense to work longer based on different factors. However, sometimes it is more beneficial to trim the flight schedule and allow the maintenance department an opportunity to continue fixing aircraft while also not risking more aircraft returning from flights with MAFs, thereby increasing the backlog of work to accomplish. The CO and AMO can declare additional maintenance days in order to improve the readiness of the squadron.

G. USMC F/A-18 SQUADRON MANNING

There are several factors that govern the manning level in a squadron, the first is the T/O. The USMC mans, staffs, and assigns Marines to squadrons in accordance with the staffing goal as set by the CMC in Marine Corps Order (MCO) 5320.12H against requirements stated in the Total Force System Management System (TFSSMS) and in accordance with the Authorized Strength Report (ASR). The ASR limits the number of Marines the USMC can afford, which depends on the end strength authorized by Congress. The ASR sets a minimum manning level at 97% of T/O for operational squadrons (CMC 2012b). As the F/A-18 has aged, the maintenance to keep an aircraft MC has increased yet manning numbers have not undergone significant changes for F/A-18 squadrons over the last seven years; in fact there has been a slight reduction (USMC 2009–2016a). This issue highlights the problem and gives rise to the question, do F/A-18 squadrons have the correct number of mechanics/technicians, CDIs and CDQARs in order to maintain readiness levels to be able to fight tonight?

H. USMC F/A-18 READINESS ISSUES

The F/A-18 Hornet is the backbone of USMC Tactical Aircraft (TACAIR) and has been deploying to the Middle East in support of Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF) since 2001 as well as continuing support of the Unit Deployment Program (UDP) to Iwakuni, Japan. The amount of flight time that has been expended on the F/A-18 over the past 15 years is far greater than initially planned or budgeted. The JSF, the F/A-18 replacement aircraft, which has been plagued by delays and cost over-runs, has not replaced the F/A-18 as quickly as planned (Mizokami 2016). These circumstances have led to the extension of the F/A-18 beyond original design specifications.

The F/A-18 was initially purchased with the expectation of being in service for 6,000 flight hours. Due to a high operational tempo and delays with the JSF, the F/A-18 service life has been extended, with some aircraft extended out to 10,000 flight hours (Myers 2015), a number that could potentially grow larger. As the F/A-18 has flown past its initial service limit, it has led to problems that were not anticipated during the acquisition process. These issues have resulted in an increase in the amount of maintenance required to keep an F/A-18 MC (F/A-18 TMS Community 2013).

In addition to increased maintenance requirements for the O-Level, Lieutenant General Jon M. Davis, USMC Deputy Commandant for Aviation (DCA) states that RBA numbers are down “due to In-Service Repairs (ISR), Out of Reporting (OOR) and Depot-level maintenance backlogs” (Davis 2015). The increase in number of repairs, delays in receiving aircraft back from PMI, while still having to maintain the timeline for sending aircraft to PMI, make it even more imperative that squadrons keep the aircraft they have on hand MC and flying.

The increase in maintenance equates to a greater number of maintenance actions that necessitate a “sign-off” by either a CDI or a CDQAR. If a squadron does not have the correct number of aircraft mechanics/technicians, CDIs, and CDQARs, it will fail to meet the requirement for aircraft readiness levels. The result is fewer MC aircraft, which reduces the available flight hours below the level in the F/A-18 Training and Readiness

(T&R) manual. The end state is aircrew become less tactically proficient and squadrons risk failing to meet their mission.

I. OBJECTIVE

The MVP is an integer linear program that provides daily fidelity and allows for a quantitative assessment to show the WCs that have sufficient manning to complete maintenance tasks and others that are overtasked in F/A-18 squadrons. Over a two-year period, the MVP provides daily assignment of maintenance activities to available Marines from each work center and experience level, with the requirement of keeping a standard number of aircraft operationally ready. MVP results show areas of deficit, either manpower or available time to complete work on aircraft. By considering results from several scenarios, MVP provides an analytic answer to: “What is the correct level of manning for an F/A-18 squadron, and is there sufficient time available to keep the aircraft MC?”

II. LITERATURE REVIEW

There has been extensive study of military aircraft maintenance, especially as it relates to deployment status and increased maintenance caused by age. However, we find no published work that uses optimization, such as the MVP, to analyze the manning levels of squadrons. Based on this review, there are no models except for MVP that allow the detailed investigation of how different manpower levels impact a squadron's ability to keep aging aircraft flying. Below, we review the related research on the amount of maintenance an aging aircraft requires and the time available to fix those aircraft.

Allen (2005) focused on the Navy Standard at-sea workweek in regards to the F/A-18C community and the hour requirement differences when on deployment and at home. In his analysis, he found the time available during a deployment workweek is slightly more than double what is available during an at-home workweek. However, the manning level for both deployment and at home is the same with the expectation of providing the same level of aircraft readiness. Allen (2005) recommends the addition of "shore-duty billets to offset spikes in squadron workload."

Additional work in this area was conducted by Matthew Dixon in 2006 while he was a student at the Pardee RAND graduate school (Dixon 2006). Dixon examined "commercial aviation data with the goal of drawing inferences and lessons about aging aircraft that may be relevant to the Air Force." While the type of aircraft he looked at has a vastly different mission than an F/A-18, he referenced a Navy study done by the Center for Naval Analyses (CNA) in 2000 (Francis and Shaw 2000). There exists a common theme between these studies that report how increasing aircraft ages increase maintenance costs as well as the maintenance requirement.

Peter Francis and Geoffrey Shaw of the CNA also did work in this area examining the "Effect of Aircraft Age on Maintenance Costs." In 1999, Dr. Raymond Pyles testified before Congress regarding the effect of aging fleets. The authors extrapolated from the data given in his testimony that "RAND expects maintenance workloads to rise by about 5 percent per year" (Francis and Shaw 2000). The authors continued this work by looking

at U.S. Navy F/A-18C aircraft from 1989–1999, while new airframes were still entering service, to see if there was an increase in maintenance costs as the platform aged. They found enough evidence to “support the conclusion that aging aircraft will require higher maintenance expenditures” (Francis and Shaw 2000).

Finally, Bell and Stucker wrote “A Technique for Determining Maintenance Manpower Requirements for Aircraft Units” for U.S. Air Force Project RAND. Their study continued research into maintenance policies and resource requirements and “presents improved methods for determining maintenance manpower levels by evaluation of existing aircraft organizations and simulation modeling” (Bell and Stucker 1971). At the time, the U.S. Air Force considered manpower utilization rates as the primary influence on manning levels. The authors continued work that began in the early 1960s of a “time-oriented, event-recording data system” as a better means to “determine the criticality of manning levels for various work centers and focuses upon personnel requirements to facilitate aircraft turn-around” (Bell and Stucker 1971). Their results did not present an answer to the question but did provide “a tool that enables the decisionmaker to examine the alternatives more clearly” (Bell and Stucker 1971).

III. PROBLEM DEFINITION AND FORMULATION

The MVP is an integer linear program with a primary objective to maximize the number of RBA days while penalizing for being below RBA requirements. The MVP assigns the hours each day that each Marine in each WC at each skill level works on each open MAF. There are constraints for the amount of time each Marine of each skill level can work each day (on open MAFs outside of other assigned duties) as well as the amount of time available to work on each aircraft each day. There are relaxations available in the form of overtime, additional manpower, and more hours to work if a day becomes a maintenance day. MVP prescribes when each maintenance day occurs.

A. PENALTIES

Not all goals for squadron maintenance can be satisfied all the time so MVP uses elastic constraints. Elastic constraints are constraints that can be violated but such violation incurs a penalty. These penalties include: being below RBA requirements; working overtime; aircraft requiring overtime; extra man-hours, which are additional man-hours beyond the capacity of the squadron; and extra aircraft hours, which are hours beyond the allowable work day per aircraft. The penalty levels for RBA depend on the number of IR each day. The penalty rates at each level of IR are defined by asking, “How many extra man-hours and maintenance hours would I be willing to ‘pay’ for an additional RBA at this level of IR?”

B. ELASTIC VARIABLES

In order to account for the need for extra maintainers, which quantifies how many additional personnel are required in a WC, an elastic variable captures the number of hours of work over and above overtime. To ensure the MVP does not allocate all the hours into one day, penalties are assessed based on increments of the quantity of additional hours. Realistically, it may be possible to borrow a maintainer from another squadron for a day or two to overcome a spike in workload, which is the first penalty level. The subsequent penalty levels support consideration for a permanent increase in manning levels.

C. MODEL ASSUMPTIONS

We assume all aircraft in an IR status start with zero open MAFs on day one. On each day, MAFs, for that day are available at the beginning of the day. Our model only considers working on aircraft that are IR, and we assume that if a particular MAF requires a part, that part is immediately available.

MVP has a piecewise linear penalty function in the objective that increases rapidly through each of the different breakpoints levels and discourages extreme deviations from several requirements. We use this structure for the required number of RBA, extra man-hours required beyond regular overtime, and extra hours required to work on an aircraft beyond available hours.

MVP does not update the status of an aircraft during a time period. In other words, the mission capability status of an aircraft at the start of the day is equal to the mission capability status at the end of the previous day. For actual operations, an aircraft can vary mission capability levels during the day. It can begin the day as FMC, fly and come back NMC with multiple MAFs, and end the day as a PMC aircraft.

D. FORMULATION

1. Sets

$j \in J$	The set of F/A-18 aircraft by Bureau Number (BUNO)	[$j1..jN$]
$k \in K$	The set of segments of piecewise linear functions	[$k1..k5$]
$m \in M$	The set of time periods (months)	[$m1..mN$]
$p \in P$	The set of maintainers ordered by increasing skill level	[mech, CDI, CDQAR]
$q \in Q$	The set of production WC	[$q120, q210, q220, q230, q310, q13B$]
$g \in G$	The set of MAFs	
$g \in G_j \subseteq G$	The set of MAFs associated with aircraft j	

$g \in GU \subseteq G$	The set of PMC MAFs	
$g \in GU_j \subseteq G$	The set of PMC MAFs associated with aircraft j	
$g \in GD \subseteq G$	The set of NMC MAFs	
$g \in GD_j \subseteq G$	The set of NMC MAFs associated with aircraft j	
$j \in J_g \subseteq J$	Aircraft j associated with MAF g	
$t \in T$	The set of time periods (days)	$[t1..tN]$
$t \in T_g \subseteq T$	The set of time periods t where work can be completed on MAF g .	
$t \in T_j \subseteq T$	The set of time periods t where aircraft j is IR status.	
$t \in T_m \subseteq T$	The set of days t associated with month m .	

2. Data

$avail_{p,q,t}$	The working hours available per Marine of skill level p , by WC q , in day t .	[hours]
b_t	The hours available to fix MAFs on aircraft j , that is MC and could be flying, in day t .	[hours]
dt	A factor multiplied by the base hours (b_t) representing the additional hours available to work on an aircraft if it is NMC.	
$ejp_{k,t}$	The penalty for working extra hours on an aircraft at breakpoint k in day t .	[RBA/hour]
$epp_{k,t}$	The penalty for working extra man-hours at breakpoint k in day t .	[RBA/hour]
fd	The amount of extra hours available to work if it is a maintenance day.	[hours]
ja_t	The number of aircraft IR in day t .	[aircraft]
$t_maint_{p,q,t}$	The number of Marines of skill level p , by WC q , in day t .	[Marines]

$m_maint_{p,q,m}$	The number of Marines of skill level p , by WC q , in month m . [Marines]
$mainthrs_{g,p,q}$	The hours required to fix MAF g , by Marine of level p , by WC q . [hours]
$minJ$	The minimum fraction of RBA, of those in IR status, required each day. [aircraft/aircraft]
mmd	The maximum number of maintenance days allowed per month. [days]
$nup_{j,t}$	The cumulative number of PMC MAFs on aircraft j in day t . [MAFs]
otd	The maximum number of overtime hours available per Marine per day. [hours]
$otjd$	The maximum number of overtime hours to work on an aircraft per day. [hours]
$otjr$	The penalty for overtime hours worked on an aircraft. [RBA/hour]
otm	The maximum number of overtime hours available per Marine per month. [hours]
$otpr$	The penalty for Marines working overtime. [RBA/hour]
$pen_{k,t}$	The penalty for being below the required RBA number at breakpoint k in day t .
$rate$	The discount factor.
rpm	The minimum readiness percentage required each month.

3. Positive Continuous Variables

$E_{k,t}$	The number of non-RBA at breakpoint k , in day t . [aircraft]
$EJ_{j,k,t}$	The extra hours worked on aircraft j , at breakpoint k , in day t . [hours]
$EP_{p,q,k,t}$	The extra man-hours worked by Marines of skill level p , in WC q , at breakpoint k , in day t . [hours]
$HDN_{g,p,p',q,t}$	The number of hours of “down” MAF g , of skill level p , completed by Marine of skill level p' , in WC q , in day t . [hours]

$HUP_{g,p,p',q,t}$ The number of hours of “up” MAF g , of skill level p , completed by Marine of skill level p' , in WC q , in day t . [hours]

$OT_{p,q,t}$ The overtime hours worked by Marine of skill level p , in WC q , in day t . [hours]

$OTJ_{j,t}$ The overtime hours worked on aircraft j in day t . [hours]

4. Binary Variables

$MD_t \in \{0,1\}$ Binary variable with value of one if day t is a maintenance day, zero otherwise.

$MOD_{j,t} \in \{0,1\}$ Binary variable with value of one if aircraft j is either NMC in day t or day t is a maintenance day, zero otherwise.

$R_{j,t} \in \{0,1\}$ Binary variable with value of one if aircraft j is RBA in day t , zero otherwise.

$YDN_{g,t} \in \{0,1\}$ Binary variable with value of one if “down” MAF g is completed in day t , zero otherwise.

$YUP_{g,t} \in \{0,1\}$ Binary variable with value of one if “up” MAF g is completed in day t , zero otherwise.

5. Formulation

$$\begin{aligned} \text{maximize } \sum_t (1 - \text{rate})^{t-1} [& \sum_{j \in T_j} R_{j,t} - \sum_k \text{pen}_{k,t} E_{k,t} - \sum_{p,q} (\text{otpr} * OT_{p,q,t} + \sum_k \text{ep}_{k,t} EP_{p,q,k,t}) \\ & - \sum_{j \in T_j} (\text{otjr} * OT_{j,t} + \sum_k \text{ej}_{k,t} EJ_{j,k,t})] \end{aligned} \quad (0)$$

$$\begin{aligned} \sum_{\substack{g \in GU \\ p: p \geq p}} HUP_{g,p,p',q,t} + \sum_{\substack{g \in GD \\ p: p \geq p}} HDN_{g,p,p',q,t} \leq & (\text{avail}_{p',q,t} + \text{fd} * MD_t) \text{maint}_{p',q,t} + OT_{p',q,t} + \sum_k EP_{p',q,k,t} \\ & \forall p' \in P, q \in Q, t \in T \end{aligned} \quad (1)$$

$$\begin{aligned} \sum_{\substack{g \in GUj \\ q \in Q \\ p, p': p \leq p'}} HUP_{g,p,p',q,t} + \sum_{\substack{g \in GDj \\ q \in Q \\ p, p': p \leq p'}} HDN_{g,p,p',q,t} \leq & b_t + (\text{MOD}_{j,t} * dt * b_t) + OT_{j,t} + \sum_k EJ_{j,k,t} \\ & \forall j \in J, t \in T \end{aligned} \quad (2)$$

$$\text{mainthrs}_{g,p,q} * YDN_{g,t} \leq \sum_{\substack{t' \leq t \\ t' \in T_g \\ p' \geq p}} HDN_{g,p,p',q,t'} \quad \forall g \in GD, q \in Q, p \in P, t \in T_g \quad (3)$$

$$\text{mainthrs}_{g,p,q} * YUP_{g,t} \leq \sum_{\substack{t' \leq t \\ t' \in T_g \\ p' \geq p}} HUP_{g,p,p',q,t'} \quad \forall g \in GU, q \in Q, p \in P, t \in T_g \quad (4)$$

$$(\text{nup}_{j,t} - 10) * R_{j,t} \leq \sum_{g \in GU \mid j \in T_g} YUP_{g,t} \quad \forall j \in J, t \in T \quad (5)$$

$$R_{j,t} \leq YDN_{g,t} \quad \forall j \in J, g \in GD, j, t \in T_g \quad (6)$$

$$YDN_{g,t} \leq YDN_{g,t+1} \quad \forall g \in GD, t \in T \quad (7)$$

$$YUP_{g,t} \leq YUP_{g,t+1} \quad \forall g \in GU, t \in T \quad (8)$$

$$\sum_{j \in T_j} R_{j,t} \geq ja_t - \sum_k E_{k,t} \quad \forall t \in T \quad (9)$$

$$\sum_{j \in T_j} R_{j,t} \geq \lceil (\text{min}J * ja_t) \rceil \quad \forall t \in T \quad (10)$$

$$\sum_{t \in T_m} R_{j,t} \geq \text{rpm} \sum_{t \in T_m} ja_t \quad \forall m \in M \quad (11)$$

$$OT_{p,q,t} \leq t_ \text{maint}_{p,q,t} * \text{otd} \quad \forall p \in P, q \in Q, t \in T \quad (12)$$

$$\sum_{t \in T_m} OT_{p,q,t} \leq m_ \text{maint}_{p,q,m} * \text{otm} \quad \forall p \in P, q \in Q, m \in M \quad (13)$$

$$OTJ_{j,t} \leq otjd \quad \forall j \in J, t \in T \quad (14)$$

$$\sum_{t \in T_m} MD_t \leq mmd \quad \forall m \in M \quad (15)$$

$$MOD_{j,t} \leq MD_{t+(1-R_{j,t})} \quad \forall j \in J, t \in T \quad (16)$$

$$E_{k,t} \geq 0 \quad \forall k \in K, t \in T \quad (17)$$

$$EJ_{j,k,t} \geq 0 \quad \forall j \in J, k \in K, t \in T \quad (18)$$

$$EP_{p,q,k,t} \geq 0 \quad \forall p \in P, q \in Q, k \in K, t \in T \quad (19)$$

$$HDN_{g,p,p',q,t} \geq 0 \quad \forall g \in GD, p \in P, q \in Q, t \in T \quad (20)$$

$$HUP_{g,p,p',q,t} \geq 0 \quad \forall g \in GU, p \in P, q \in Q, t \in T \quad (21)$$

$$MD_t \in \{0,1\} \quad \forall t \in T \quad (22)$$

$$MOD_{j,t} \in \{0,1\} \quad \forall j \in J, t \in T \quad (23)$$

$$OT_{p,q,t} \geq 0 \quad \forall p \in P, q \in Q, t \in T \quad (24)$$

$$OTJ_{j,t} \geq 0 \quad \forall j \in J, t \in T \quad (25)$$

$$R_{j,t} \in \{0,1\} \quad \forall j \in J, t \in T \quad (26)$$

$$YDN_{g,t} \in \{0,1\} \quad \forall g \in GD, t \in T \quad (27)$$

$$YUP_{g,t} \in \{0,1\} \quad \forall g \in GU, t \in T \quad (28)$$

Constraint set (1) ensures the hours worked by Marines do not exceed the hours available, to include overtime and the elastic variables. Constraint set (2) ensures the hours worked on aircraft do not exceed the hours available, to include overtime and the elastic variables. Constraint sets (3) and (4) keep track of the hours on each MAF and change the MAF status to complete after the accumulation of sufficient hours. Constraint set (5) declares an aircraft NMC if there are more than ten PMC MAFs and constraint set (6) declares an aircraft NMC if there is at least one NMC MAF. Constraint sets (7) and (8) ensure a MAF that is “signed-off” remains “signed-off.” Constraint sets (9), (10), and (11) balance the number of MC aircraft with the overall number of IR aircraft and enforce minimum RBA and readiness percentage levels.

Constraint sets (12), (13), and (14) set bounds for the amount of overtime available daily and monthly. Constraint sets (15) and (16) limit the number of maintenance days and provide extra hours to work on aircraft if the time period is a maintenance day or an aircraft is NMC. Constraint sets (17) through (28) identify binary or positive variables.

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IV. IMPLEMENTATION, RESULTS, AND ANALYSIS

The data for this thesis is historical maintenance data from the Decision Knowledge Programming for Logistics Analysis and Technical Evaluation (DECKPLATE) (NAVAIR 2016a) reporting system for five USMC F/A-18 squadrons. The data covers a two year period, August 1, 2013 to July 31, 2015, for four squadrons and a 22 month period, August 1, 2013 to May 31, 2015, for the fifth squadron. Four squadrons belong to Marine Aircraft Group (MAG) 31 stationed at Marine Corps Air Station (MCAS) Beaufort, South Carolina; VMFA-115, VMFA-122, VMFA(AW)-224, and VMFA(AW)-533. The fifth squadron, which belongs to MAG-12 at MCAS Iwakuni, Japan, is VMFA(AW)-242. VMFA-115 flies the F/A-18A++, VMFA-122 flies the F/A-18C, and the other three squadrons fly the F/A-18D. The four MAG-31 squadrons conduct deployments in support of OEF as well as UDP whereas VMFA(AW)-242 permanently resides in Iwakuni, Japan and conducts detachments throughout the Pacific Area of Responsibility.

The MVP looks at squadrons individually over the entire time period utilizing the manpower, aircraft in the squadron, and the historical maintenance workload. For example, as shown in Table 1, VMFA(AW)-242 has 17,953 MAFs over 440 days on 15 aircraft. As aircraft sometimes change squadrons, the total aircraft is how many had recorded MAFs during the time period but each squadron has a maximum of 15 to work on at any one time. Out of computational necessity, MVP divides each squadron's data into four instances with each covering at most six months.

Table 1. MAFs, Time Period Covered, and Number of Aircraft per Squadron. Adapted from DECKPLATE.

Squadron	# of MAFs	Days	Total Aircraft Assigned during Period	Max IR Aircraft at one time
VMFA-115	16,341	476	22	14
VMFA-122	16,233	484	24	15
VMFA(AW)-224	18,014	483	23	12
VMFA(AW)-242	17,953	440	15	14
VMFA(AW)-533	13,467	476	21	13

There are large variations in the amount of MAFs each squadron has as well as the amount of total hour requirements for those MAFs. In particular, VMFA(AW)-242 has the second-highest number of MAFs despite a time period that is roughly 40 days shorter than the other four squadrons while also in the top three of hour requirements in 14 of the 18 skill levels across all six WCs. One factor affecting this is the amount of hours each squadron flies which has a direct impact on the amount of maintenance. For each squadron, Table 2 breaks down the monthly summary statistics and Figure 4 shows the monthly flight hours for the entire two year period.

Table 2. Monthly Summary Statistics of Squadron Flight Hours from Aug 1, 2013 – Jul 31, 2015. Adapted from DECKPLATE.

Squadron	Mean	Median	Standard Deviation	Minimum	Maximum	Total Hours
VMFA-115	212.4	201.3	90.9	73.2	377.1	5097.5
VMFA-122	194.7	155	100	79.5	500.9	4673.7
VMFA(AW)-224	200.3	165.7	105	51.7	438.7	4807.4
VMFA(AW)-242	291.8	289	54.5	177.7	404.3	7002.1
VMFA(AW)-533	195.1	184.2	80.2	85.9	407.5	4682.6

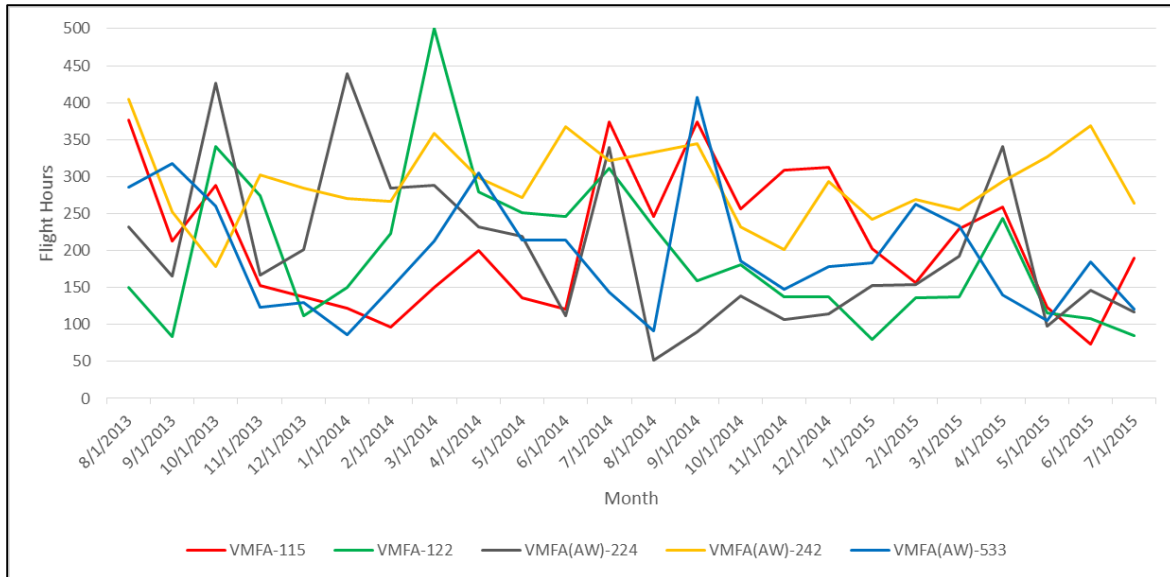


Figure 4. Squadron Flight hours from Aug 1, 2013 – Jul 31, 2015. Adapted from DECKPLATE.

VMFA(AW)-242 does not have the highest number of flight hours in a month but over the time period it sustains a high number of flight hours with the smallest deviation. Overall, VMFA(AW)-242 flies greater than 1,900 hours more than any of the other squadrons. Therefore, due to a higher utilization of aircraft, VMFA(AW)-242 incurs more planned maintenance.

The MVP is implemented in the General Algebraic Modeling System (GAMS) using CPLEX on a Dell desktop with two 2.3 GHz processors and 128 GB of RAM. We solve a six-month MVP instance using a solution cascade (Baker 1997) with a three month window with a one month advance. Depending on the squadron and instance, the MVP has between 717,000 and 2.9 million variables, of which roughly 70,000 are discrete, and the solution time varies between 5.5 and almost 21 hours. Due to the magnitude of the MVP, each cascade instance is limited to the first solution found that is guaranteed to be within 10% of the optimal solution or two hours.

A. DATA

The data used for this thesis is from multiple sources. The number of personnel, to include the numbers of CDIs and CDQARs in each WC, is from the Marine Aviation

Commanders' Current Readiness Assessment Tool (MACCRAT) (USMC 2016b), an Access database with monthly entries. For any missing data, we use squadron level documents to fill in the missing values. The Marines in the quality assurance WC are CDQARs in their MOS but they are not included directly in MVP because their responsibilities involve more supervision and training than conducting maintenance. Squadron maintenance data is from DECKPLATE.

1. Assumptions

There are several assumptions regarding maintenance execution and manpower management in an F/A-18 squadron. These range from the number of Marines at work each day, to the number of usable hours they have to work, to the number of hours an aircraft is available for maintenance. We use the following data assumptions:

- The number of maintainers, to include mechanics, CDIs and CDQARs, remains constant throughout a month.
- Squadrons normally have to provide Marines for the Fleet Assistance Program (FAP), where they work at other offices on base. FAPs remove personnel from squadron manpower, generally 2–5 Marines, but those reductions are not accounted for in the manning data.
- The squadron can work a 12 on/12 off schedule at most 4 days per month or one full day on the weekend, for a maximum of 10 hours of monthly overtime.
- Parts for each MAF are always available.
- An aircraft is MC once a NMC MAF is “signed-off,” there is no additional delay for a FCF.
- An aircraft is OOR if undergoing an ISR or PMI, otherwise it is IR.
- An OOR aircraft is removed from the available aircraft to work on and is not part of the readiness calculation.
- The minimum number of RBA each day is 40% of the number of IR aircraft.
- The minimum monthly RBA is 75% of the number of IR aircraft.
- There are other significant demands on maintainer's time detailed in section 4 of this chapter.

2. Manpower Requirements

The maintenance data from DECKPLATE is for all aircraft assigned during the period, for every WC, and for all gear that have a maintenance cycle to maintain. As this thesis is only analyzing the six production WCs, we remove all other WC MAFs. We also remove MAFs that do not belong to aircraft, such as those for ground support equipment.

There are several steps to calculate the number of hours for each skill level for each MAF. DECKPLATE provides two columns that capture time use for a MAF, Elapsed Maintenance Time (EMT) and Man-hours. EMT is the “number of clock hours involved in making the repair,” or the amount of time each maintainer works, and Man-hours is “the number of man-hours that were expended to correct the discrepancy” (Commander Naval Air Forces [CNAF] 2013), which is the total hours for all maintainers that work on a MAF. The first step is to calculate the number of workers on each MAF by dividing the Man-hours by EMT. As CDIs and CDQARs are not allowed to inspect their own work (CNAF 2013), the result should be a whole number. When the result is not a whole number, the result is rounded to the nearest whole number. Subsequently, depending on whether a CDQAR is required for the MAF, a one is entered in the CDI or CDQAR column and the mechanic column becomes one less than the total number of workers. Finally, the resulting quantities are multiplied by EMT to get the hours for each skill level for each MAF, as shown in Table 3. Utilizing this method, the hours for the total period across all MAFs for each WC, skill level, and squadron are illustrated in Figures 5, 6, and 7.

Table 3. Snapshot of Maintenance Data from VMFA(AW)-242. Adapted from DECKPLATE.

Rcvd Date	WC	BUNO	Manhours	EMT	mech	CDI	CDQAR	Up/Down Ind	MAF	QAR Reqd
Aug 8, 2013	q310	j165529	0.2	0.1	0.1	0.1	0.0	D	GF7220260_3KYBXER	N
Aug 8, 2013	q310	j165529	0.4	0.4	0.0	0.4	0.0	D	GF7220268_3KYBXH8	N
Aug 8, 2013	q310	j165529	17.5	6	12.0	6.0	0.0	D	GF7220259_3KYBXEQ	N
Aug 8, 2013	q120	j165531	3.7	2.7	0.0	2.7	0.0	D	GF7220265_3KYBXGM	N
Aug 8, 2013	q220	j165531	0.9	0.9	0.0	0.9	0.0	D	GF7220267_3KYBXH5	N
Aug 8, 2013	q210	j165685	0.1	0.1	0.0	0.1	0.0	U	GF7220287_3KYBXKM	N
Aug 8, 2013	q220	j165685	1	1	0.0	1.0	0.0	U	GF7220286_3KYBXKG	N
Aug 8, 2013	q210	j165686	0.1	0.1	0.0	0.1	0.0	U	GF7220288_3KYBXJL	N
Aug 9, 2013	q120	j164667	2.9	2.9	0.0	0.0	2.9	D	GF7221328_3KYBXPO	Y
Aug 9, 2013	q120	j164667	18.4	6.9	13.8	0.0	6.9	D	GF7221311_3KYBXN9	Y
Aug 9, 2013	q13B	j164653	4.6	3.6	0.0	3.6	0.0	U	GF7221314_3KYBXO2	N
Aug 9, 2013	q210	j164653	0.1	0.1	0.0	0.1	0.0	U	GF7221314_3KYBXO3	N
Aug 9, 2013	q220	j164653	3.2	1.6	1.6	1.6	0.0	D	GF7221314_3KYBXO0	N
Aug 9, 2013	q310	j164653	4.1	1.7	1.7	1.7	0.0	D	GF7221315_3KYBXO1	N
Aug 9, 2013	q120	j164659	2.1	1.1	1.1	1.1	0.0	D	GF7221295_3KYBXC	N

For example, utilizing the first row, the MAF was received on August 8, 2013, “q310” is the Powerline WC, and “j165529” identifies the aircraft. Next, 0.2 is the total hours required on the MAF and 0.1 is the EMT used per qualification level. There is a 0.1 in both the mech and CDI columns, signifying the time required for each skill level, and a 0.0 in the CDQAR column because the CDQAR is not required for this MAF. The “D” indicates it is an NMC MAF, “GF7220260_3KYBXER” is the MAF identifier, and “N” in the “QAR Reqd” column indicates no CDQAR is required to “sign-off” the MAF.

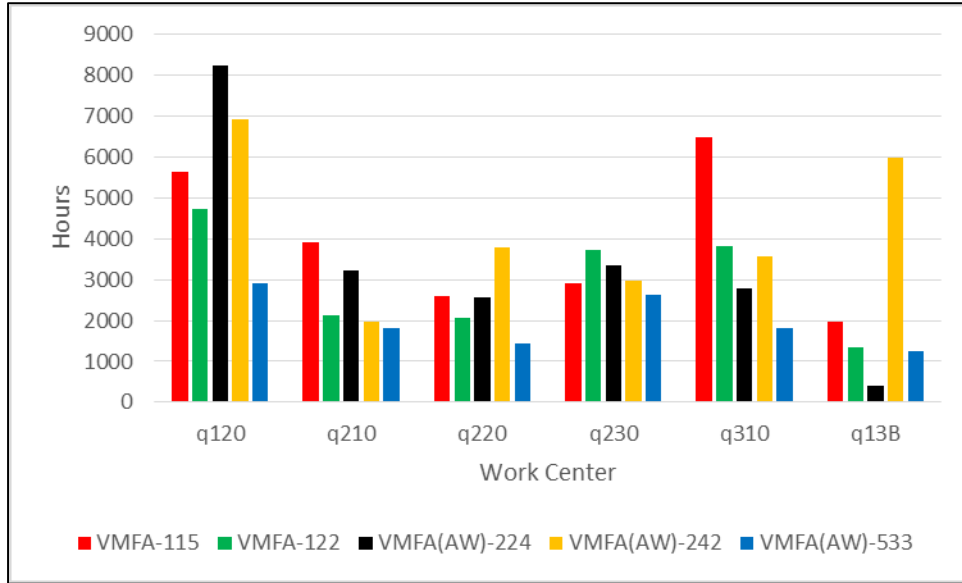


Figure 5. Total Hours Required for Mechanics For All Squadrons. Adapted from DECKPLATE.

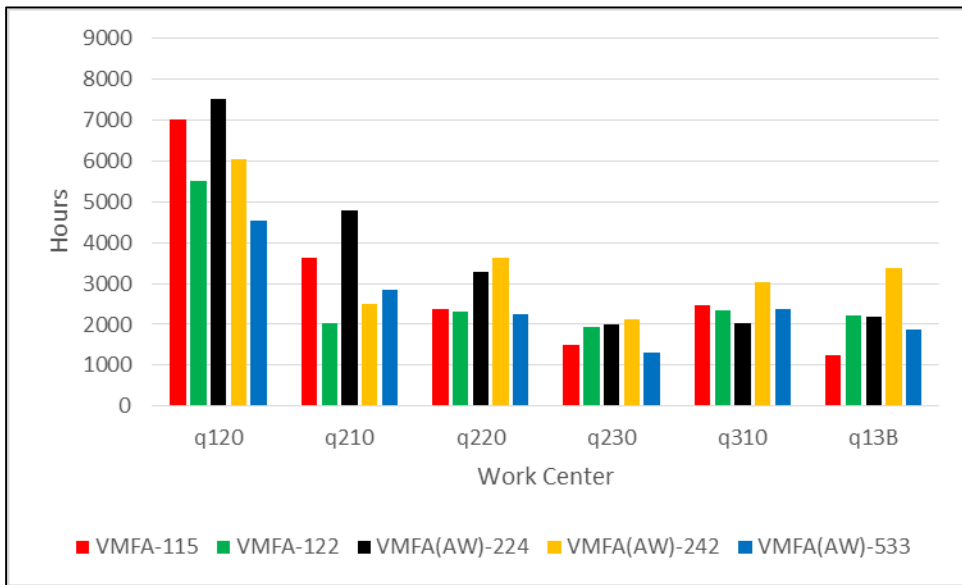


Figure 6. Total Hours Required for CDIs for All Squadrons. Adapted from DECKPLATE.

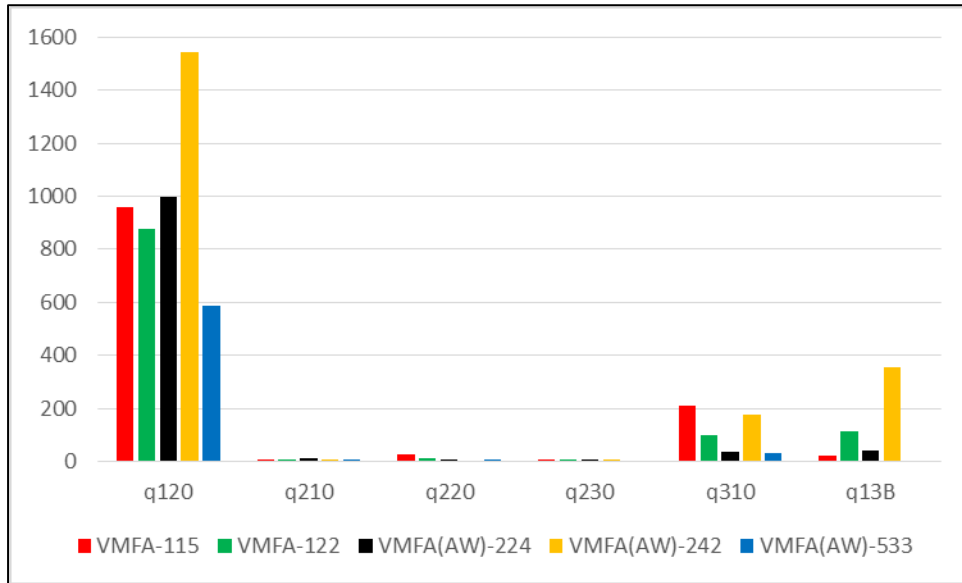


Figure 7. Total Hours Required for CDQARs for All Squadrons. Adapted from DECKPLATE.

3. Dates

There is also a requirement to modify the entry date for a MAF. As the MVP uses work days and not calendar days, adjustments are made for MAFs that occur on non-working days. Squadrons submit daily maintenance readiness reports, using the Aviation Management Supply and Readiness Reporting (AMSRR) system, to higher headquarters for every working day, roughly 240 per year. Squadrons do not generally conduct maintenance on weekends or holidays and because those are not working days, there is no requirement for an AMSRR. However, squadrons frequently conduct flight operations on weekends and holidays. When aircraft return, aircrew enter MAFs and the time stamp reflects that day, whether it is a work day or not. As the MVP only considers working days as days a squadron submits an AMSRR, MAFs require alignment which consists of advancing the entry date to the next day the squadron submits an AMSRR.

4. Work Day

The number most important in determining whether an F/A-18 squadron has the correct level of manning is the amount of time available to conduct maintenance. There are many time requirements for Marines throughout the day, month, and year above and

beyond the job of fixing aircraft. We made the breakdown in Table 4 using the following assumptions:

- Day crew is manned with 60% of maintainers, night crew with 40%.
- The squadron conducts two day launches and one night launch daily and each launch consists of six aircraft.
- Marines have various time constraints, including but not limited to: standing duty, conducting military training, attending formation, going on leave, and many others that reduce the time available to work on aircraft.

Table 4. Breakdown of Available Man-Hours per Workday.

Available Man-hours per Workday			
	Day Crew	Night Crew	
Start	0700	1630	
End	1630	0200	
Work Day (Available Hours)			
Total hours available on normal day	9.5	9.5	Average work day, not 12 on/12 off
% breakdown of manning	60.00%	40.00%	Day crew has higher percentage of personnel
Number of aircraft launches	2	1	2 day lunches and 1 night launch
Hours required per launch	1.3	1.3	Setting up/troubleshooting/catching the aircraft. CDI on that shift is out
Total hours set for launch	2.6	1.3	there 45 min prior until 30 min after, no work.
FOD Walk	0.3	0	Day crew does FOD Walk, night crew does not.
Chow	0.5	0.5	Does not include any other administrative breaks
Maintenance Meeting	0.3	0.3	No work is conducted during maintenance meeting
Miscellaneous (waiting for parts, tool checkout, etc)	0.8	0.8	Many other instances this could involve
Daily Total hours not used on Maintenance	4.5	2.9	
Total daily hours available for Maintenance	5	6.6	Leftover hours you can be in work on MAF's
Average days in a month at work	20.08	20.08	With 482 AMSRRs published in a 2 year period, 241/year ~ 20 per month
Monthly Total Hours Available	100.4	132.5	
Training/Formations/Duty/Leave (Used Hours)			
Tech Training (2hrs/week, 4 week/month)	8	8	Tech training is 2 hours per shift per week, 8 hours per month
Ground Training (min per month)	1	1	At a minimum, there is 1 hour of ground training (MarineNet, SAPR, etc)
Formation (1 per month)	1	1	At a minimum, 1 monthly all hands formation
Duty	4.6	6.4	Once per month
Leave (30/year = 2.5/month)	12.5	16.5	Every Marine earns 2.5 days of leave per month.
Monthly Total Hours Unavailable	27.1	32.9	
Monthly Total Hours Available	100.4	132.528	
Total Unavailable hours per month	27.1	32.9	
Actual Monthly Hours Available	73.3	99.6	Total monthly hours leftover after accounting for Used Hours
Average available hours/day (20 days in month)	3.7	5.0	Average hours available for a 20 day working month
Available daily hours per mechanic and CDI		4.2	Averaged using 60% for day crew, 40% for night crew
Available daily hours per CDQAR		3.2	

By aggregating over a year, the end result is a mechanic/technician or CDI has 4.2 usable hours to conduct maintenance per work day. The CDQAR, who is generally a higher rank with more responsibilities such as Division Chief and/or a maintenance program manager, has more time requirements and only has 3.2 usable hours to conduct maintenance per day. If the CO decides to use overtime, there is a maximum of an

additional 2.5 hours per day per Marine of work that can be done, with a monthly maximum of ten hours.

There is also a limit on the number of hours maintainers can work on an aircraft in a day. Squadrons target between 285–325 flight hours per month in order to meet T&R requirements and using an average flight time of 1.3 hours equates to 220–250 sorties per month. Taking into account maintenance days, weather cancellations, and other variables throughout a month, scheduling 18 sorties per day, Monday through Friday, enables meeting the flight hour goal. We break down the time an aircraft is on the ground and maintainers can conduct maintenance in Table 5.

Table 5. Available Daily Hours for Aircraft Maintenance.

Aircraft		
Flight Time	1.3	Per T&R, average flight is 1.3 hours
Number of flights	3	3 launches per day
Total Flight Time	3.9	Sum
Unavailable (45 min prior to launch)	0.7	Aircraft is prepped and no MAFs in work 45 min prior to launch
Total for 3 flights	2.1	Sum
Unavailable (30 min after landing)	0.5	Accounts for taxi, shut down and maintenance debrief, no work being done
Total for 3 flights	1.5	Sum for 3 landings
Total Unavailable Hours	7.5	Sum
Hours aircraft is available if not flying	19	0700-0200 daily work schedule
Hours aircraft is available if flying	11.5	Base amount of time available if conducting all 3 sorties

The hours an aircraft is available is as important, if not more so, than the hours Marines have to work. If an aircraft is MC the MVP considers it to be flying or available to fly and only has 11.5 hours available for maintenance per day. If an aircraft is down, or it is a maintenance day, the aircraft has 19 hours available for maintenance per day. If the CO decides to work overtime, there is a maximum of an additional five hours each day per aircraft of maintenance time.

5. Parts Availability

Somewhat unrealistically, MVP assumes a part is available immediately. There are three categories of parts availability. The first is parts that are on hand at a squadron, such as tires or smaller consumables. The next category is parts that are located at the MALS supply division and MALS delivers them when a squadron places a part on order.

Ideally parts arrive at the squadron within an hour and some delivery time is accounted for in the work day assumption. The third category is parts that are not in stock. The delay for these parts can vary significantly, with some parts requiring shipping from far away locations to other parts that are no longer made and replacements are sourced from F/A-18s that are no longer airworthy and are either at a museum or the boneyard.

For aircraft that are NMC and require a part that is not in stock the aircraft is Non-Mission Capable Supply (NMCS). NMCS is becoming more of an issue as the F/A-18 is aging and parts are not available to the point where, “Sometimes it takes the Marines 18 months to get parts for early model F-18 jets whose production was halted in 2001” (Tomlinson and Griffin 2016). For the time period of this thesis, the daily squadron average of NMCS aircraft is between 11.9% and 15.9% (NAVAIR 2016a). VMFA(AW)-242 has a higher priority for parts due to being stationed in Japan and it averages 14.4% NMCS during the entire period, shown in Figure 8 (all figures for VMFA(AW)-242 display the squadron patch in the upper right corner).

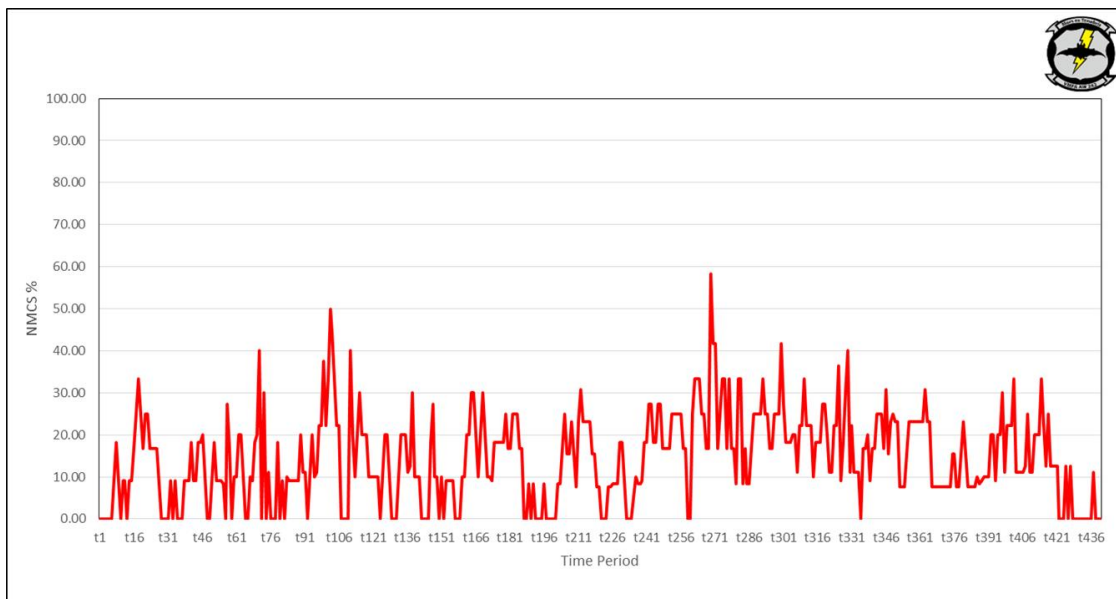


Figure 8. VMFA(AW)-242 NMCS from Aug 1, 2013 – Jul 31, 2015.
Source: DECKPLATE 2016.

B. PENALTY ASSESSMENT

There are five penalties assessed in our objective function; two have constant slope and three are piecewise linear. The two constant penalties are for overtime hours for personnel and overtime hours for working on an aircraft, with the same penalty assessment for each hour. The three piecewise linear penalties are: being below required RBA, requiring extra man-hours, and requiring extra hours to work on an aircraft. Tables 6 and 7 show the penalty levels and tolerances for all three piecewise penalties.

Table 6. Break Points for RBA Penalties

Number of IR Penalty Level	7, 8	9, 10	> 11
1	7	8	9
2	6	7	8
3	5	6	7
4	4	5	6
5	<4	<5	<6

The Number of Aircraft at Which a Penalty Level Begins. For Example, in a Squadron with 11 Aircraft IR, Penalty Level 3 Is Used If There Are 7 RBA.

Table 7. Piecewise Penalty Levels for Number of Extra Man-Hours Required and Number of Extra Hours Required to Work on an Aircraft.

Penalty Level	Lower Bound (hrs)	Upper Bound (hrs)
1	0	< 5
2	5	< 10
3	10	< 15
4	15	< 20
5	20	∞

C. RESULTS

MVP’s daily RBA requirement of 40% and monthly RBA requirement of 75% cause the MVP to produce higher readiness rates than actually observed in the five squadrons. MVP easily accepts other RBA requirements but keeping these higher readiness rates compensates somewhat for the assumed parts availability.

Each squadron undergoes two scenarios of the MVP. The first scenario allows the MVP to utilize one maintenance day each month and the second scenario allows the MVP to utilize two maintenance days each month, with no other changes. The focus squadron for displaying results and additional scenarios is VMFA(AW)-242 as the squadron has the highest number of flight hours and also the lowest volatility in terms of aircraft being assigned and reassigned.

1. RBA Percentage

The MVP uses available resources as well as elastic variables to ensure the minimum daily RBA percentage is 40% of the IR aircraft. The MVP also ensures the monthly RBA percentage rate is 75% of the IR aircraft, which is the MC goal stated in the F/A-18A/B/C/D Mission Essential Subsystem Matrix (MESM) (CNAF 2009).

All five squadrons attain the daily and monthly RBA percentage goals with varying utilization levels of overtime and extra time. Figures 9 and 10 show the daily RBA percentage in black and the monthly RBA percentage in red for VMFA(AW)-242 for one and two maintenance days resulting from MVP. Figure 11 shows the monthly RBA percentage for scenarios using one and two maintenance days as well as the historical RBA percentage.

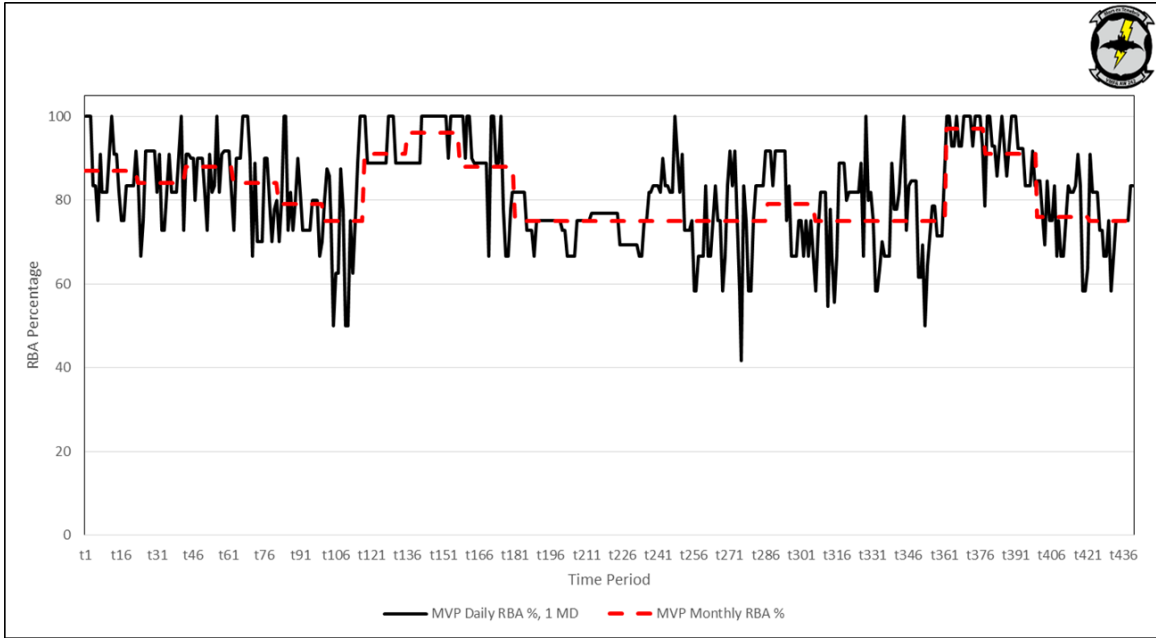


Figure 9. VMFA(AW)-242 RBA Percentage, One Maintenance Day.

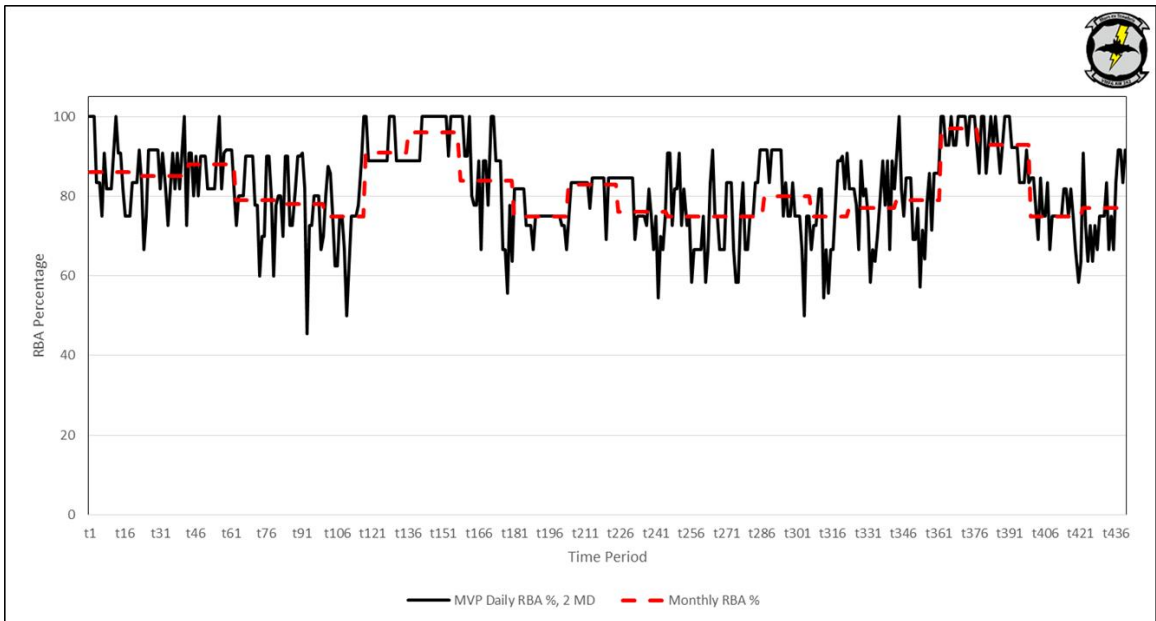


Figure 10. VMFA(AW)-242 RBA Percentage, Two Maintenance Days.

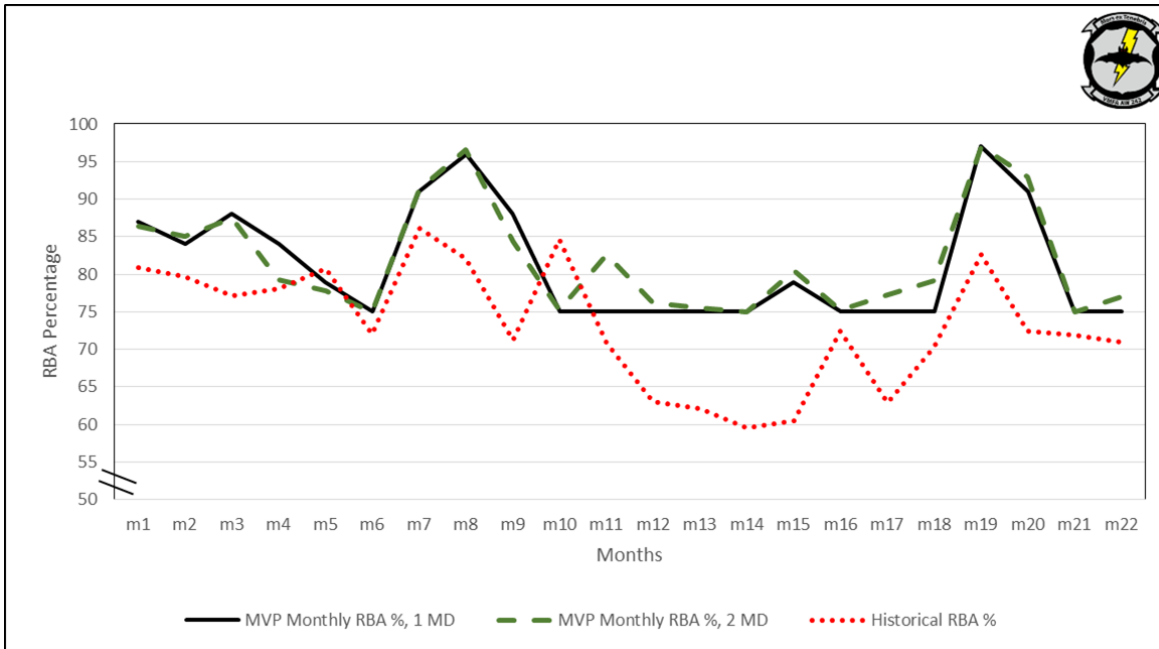


Figure 11. VMFA(AW)-242 Monthly RBA Percentage: One Maintenance Day, Two Maintenance Days, and Historical.

The other squadrons have similar results but the big difference is the volatility of the excursions in historical RBA percentage. For example, as demonstrated in Figure 9, VMFA(AW)-242 comes very close to 40% RBA on a couple of days, but VMFA(AW)-533 has multiple days of 20% RBA and VMFA-115 drops to 0% on two days.

2. Aircraft Overtime and Extra Time

In order for the MVP to meet the 40% daily and 75% monthly RBA requirements it utilizes overtime and extra time to conduct maintenance on aircraft. Overtime is a maximum of five hours available each day, extra time is hours above and beyond the overtime that may not be physically accomplished. The elastic variable for extra time is extremely important in determining if there is enough time to fix aircraft given the current utilization rates.

Figure 12 shows aircraft BUNO 165528 from VMFA(AW)-242 and how much overtime, in gold, and extra time, in red, the MVP uses throughout the time period for the one maintenance day scenario resulting from MVP. Figure 13 contains the same data just

condensed to the actual days there is overtime and extra time. Figures 14 and 15 reflect the same aircraft using the two maintenance day scenario.

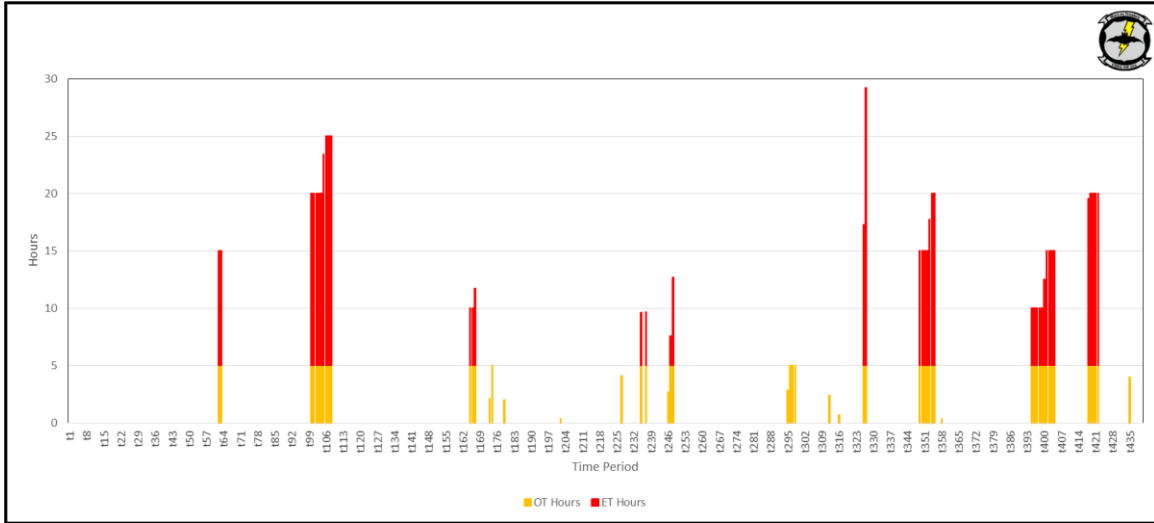


Figure 12. VMFA(AW)-242, BUNO 165528, Overtime and Extra Time Hours Required, One Maintenance Day (OT Is Overtime and ET Is Extra Time).

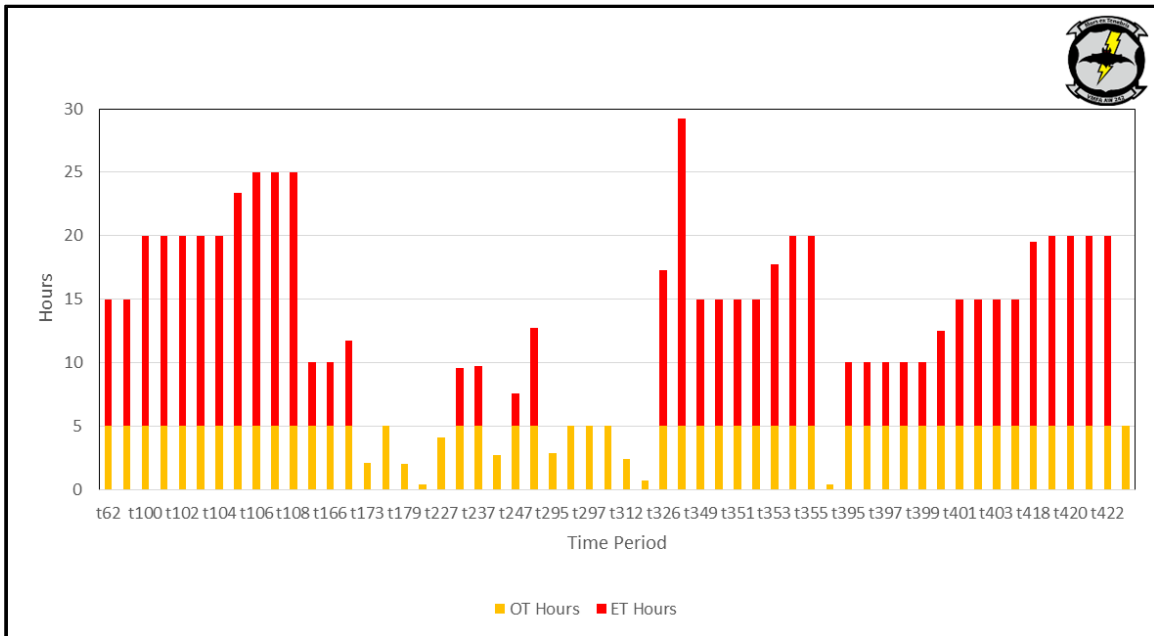


Figure 13. VMFA(AW)-242, BUNO 165528, Overtime and Extra Time Hours Required, One Maintenance Day, with Zero-Hour Days Removed.

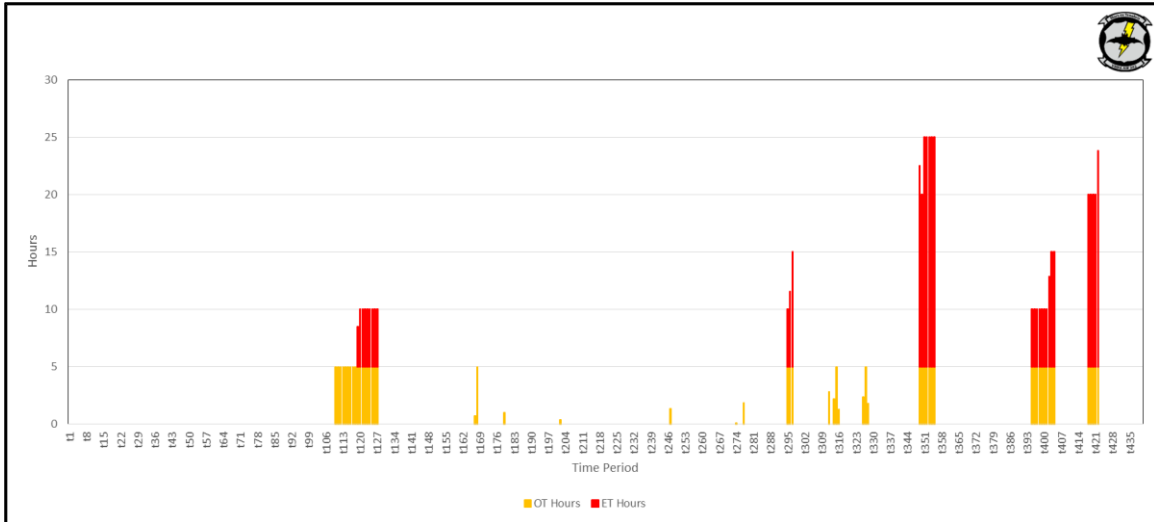


Figure 14. VMFA(AW)-242, BUNO 165528, Overtime and Extra Time Hours Required, Two Maintenance Days.

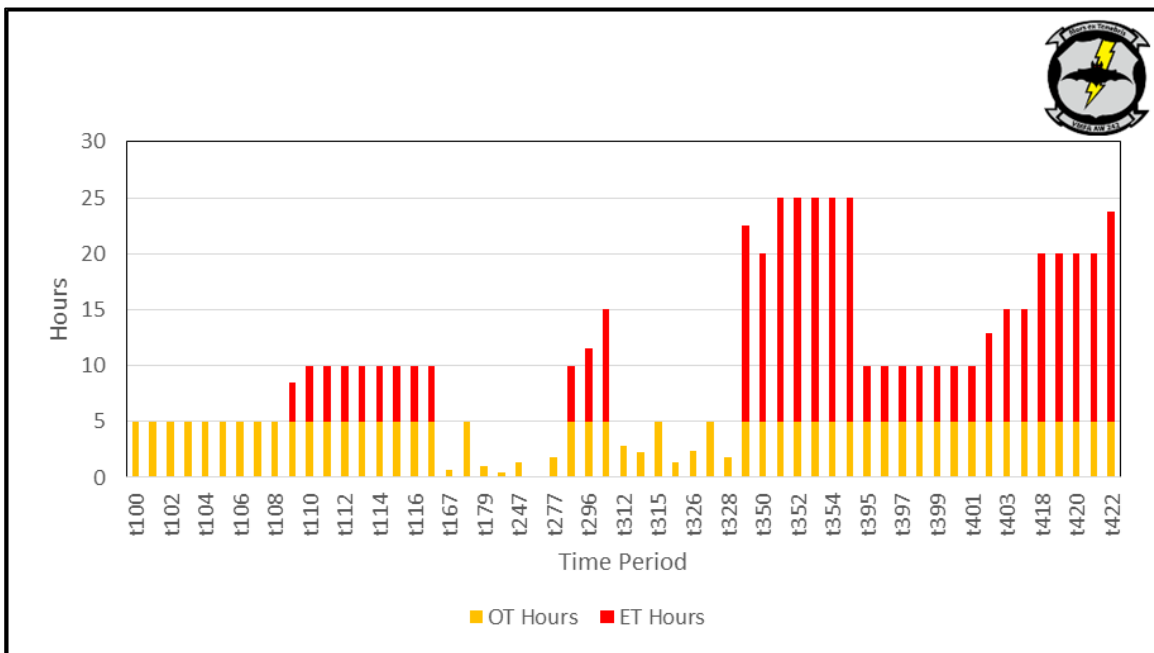


Figure 15. VMFA(AW)-242, BUNO 165528, Overtime and Extra Time Hours Required, Two Maintenance Days, with Zero-Hour Days Removed.

While there is still a need for overtime and extra time with two maintenance days, the amount is significantly less. BUNO 165528 is representative of the average overtime

and extra time requirement in VMFA(AW)-242. All squadrons utilize overtime and extra time in the MVP with some requiring a far greater number and others somewhat less. Without using extra time on these aircraft, and if the 40% daily and 75% monthly RBA requirements are removed, the RBA rates fall below those shown in Figures 9 and 10.

3. Personnel Overtime and Extra Time

In addition to aircraft overtime and extra time, personnel require overtime and extra time in order to meet the RBA requirements set in the MVP. Personnel overtime has a daily maximum of 2.5 hours and a monthly maximum of 10 hours.

The elastic variable for personnel is easier to understand than the one for aircraft because the extra hours are possible with additional personnel. There are certainly excursions where it is not possible to provide an additional 20 man-hours in one day without a substantial increase in the manning level but it does highlight there is an abundance of work assigned to that WC and insufficient personnel available.

Across all five squadrons extra time is used in all WCs to varying degrees. Through all three skill levels, in all five squadrons, in WCs 210, 220, 230, and 310, the highest total of extra hours used is 35 hours. While those hours are necessary for completion of MAFs, it is possible to utilize the senior personnel in the quality assurance WC or even borrow a Marine from an adjacent squadron for a few hours. However, the remaining two WCs are vastly different.

The extra hour requirements for WCs 120 and 13B are much higher than the other four production WCs. Two of the five squadrons require more than 100 extra hours over the entire time period in different skill levels in WC 120 for the one maintenance day scenario and one squadron still requires extra hours in the two maintenance day scenario. For WC 13B, one squadron requires significant extra hours for all three skill levels in the one maintenance day scenario and while the amount is reduced in the two maintenance day scenario, the mechanic and CDI skill levels still require more than 50 extra hours. For both of these WCs there is also a significant amount of overtime used, far greater than any other WC. Figure 16 shows the overtime and extra time for all skill levels in WC 120 in VMFA(AW)-242 for one maintenance day and Figure 17 shows two

maintenance days, both for the entire time period. For WC 13B, there is a significant hours requirement for all skill levels. Figures 18–21 show the overtime and extra time for the CDQAR level in WC 13B for both scenarios and Table 8 displays the hours for all skill levels and both scenarios in WC 13B.

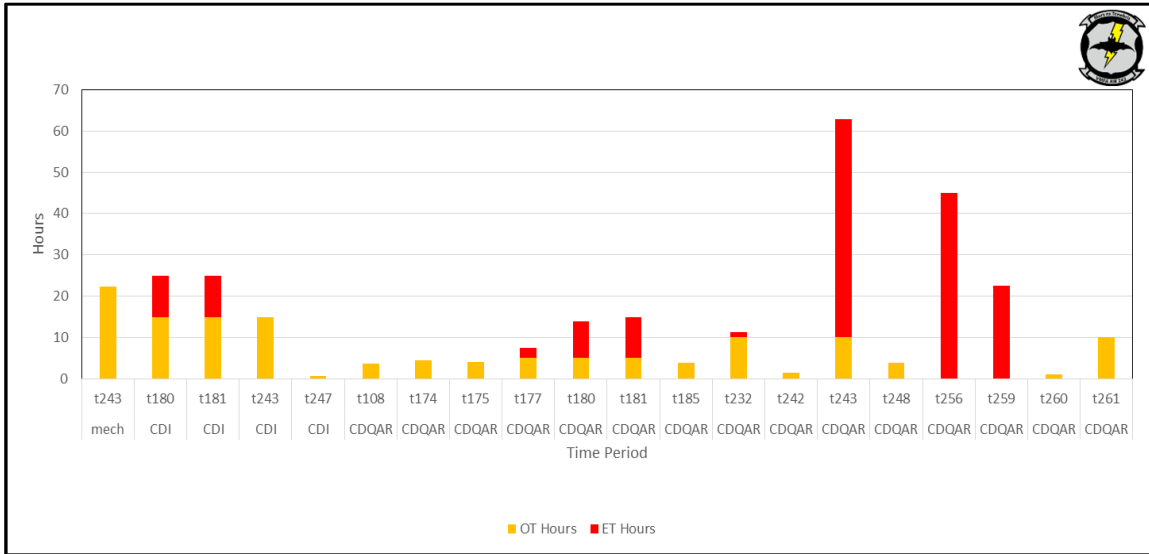


Figure 16. VMFA(AW)-242, WC 120, All Skill Levels, One Maintenance Day.

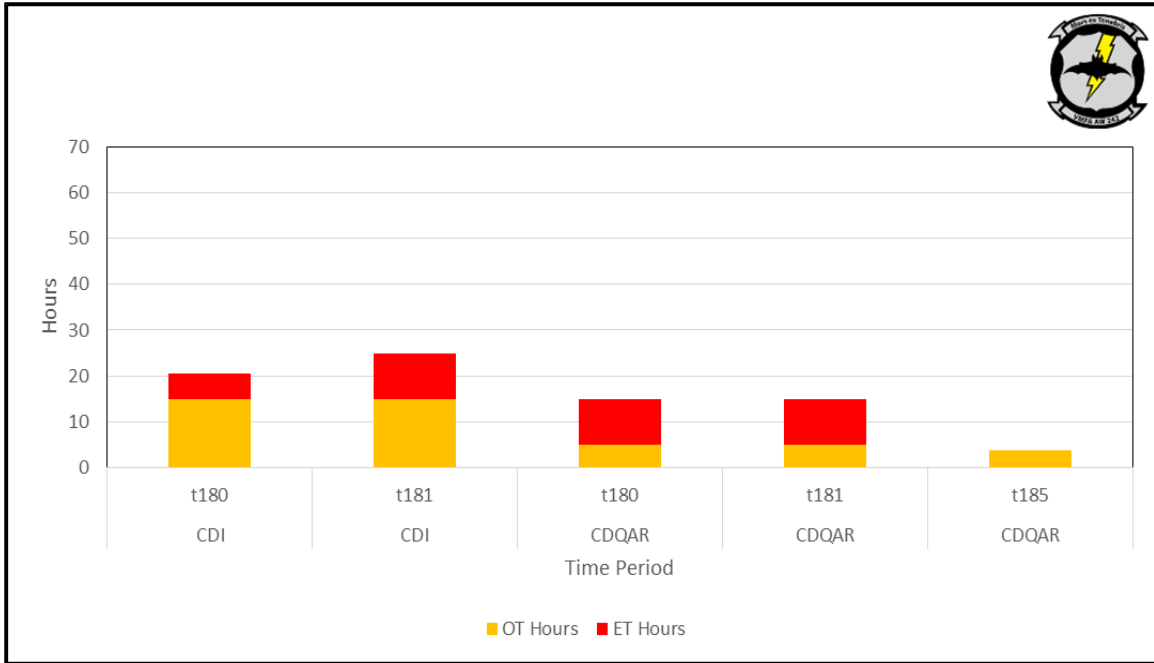


Figure 17. VMFA(AW)-242, WC 120, All Skill Levels, Two Maintenance Days.

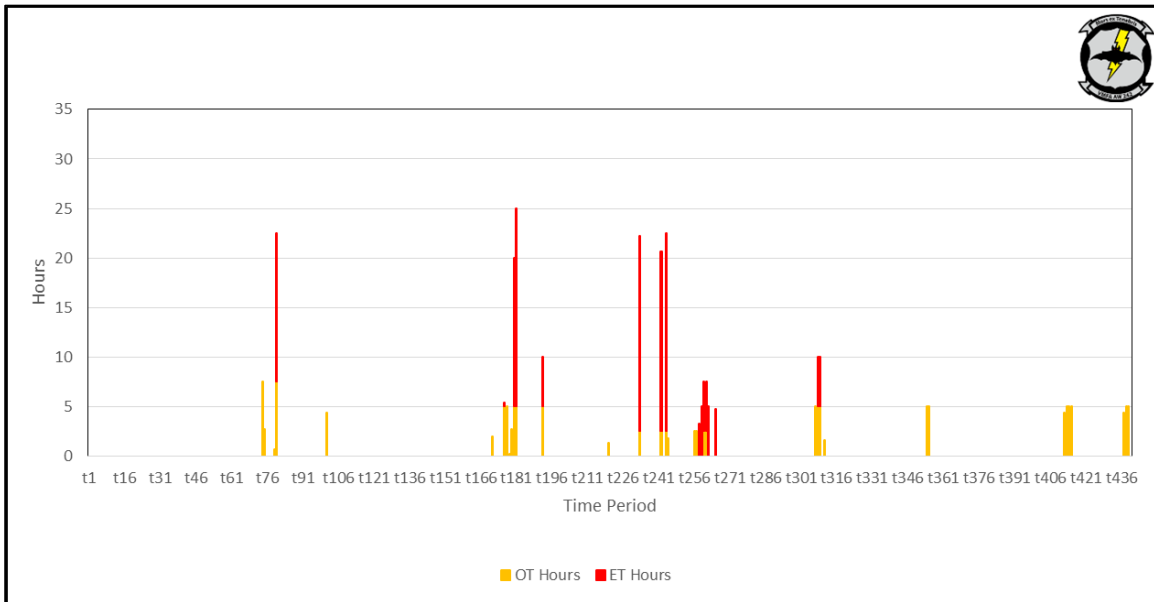


Figure 18. VMFA(AW)-242, WC 13B, CDQAR, Overtime and Extra Time Hours Required, One Maintenance Day

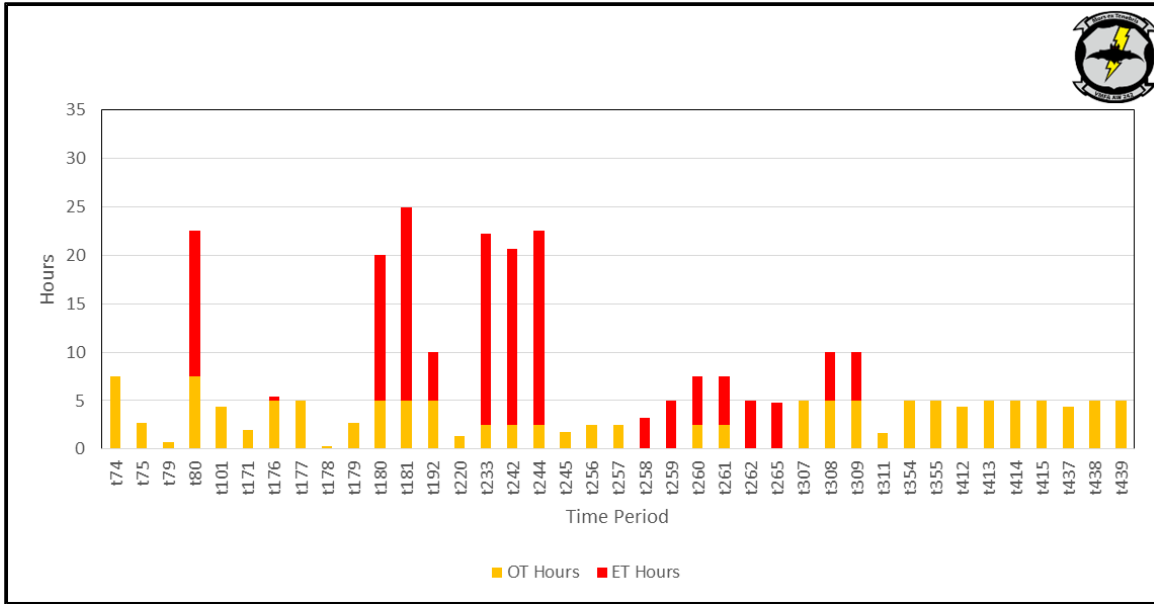


Figure 19. VMFA(AW)-242, WC 13B, CDQAR, Overtime and Extra Time Hours Required, One Maintenance Day, with Zero-Hour Days Removed.

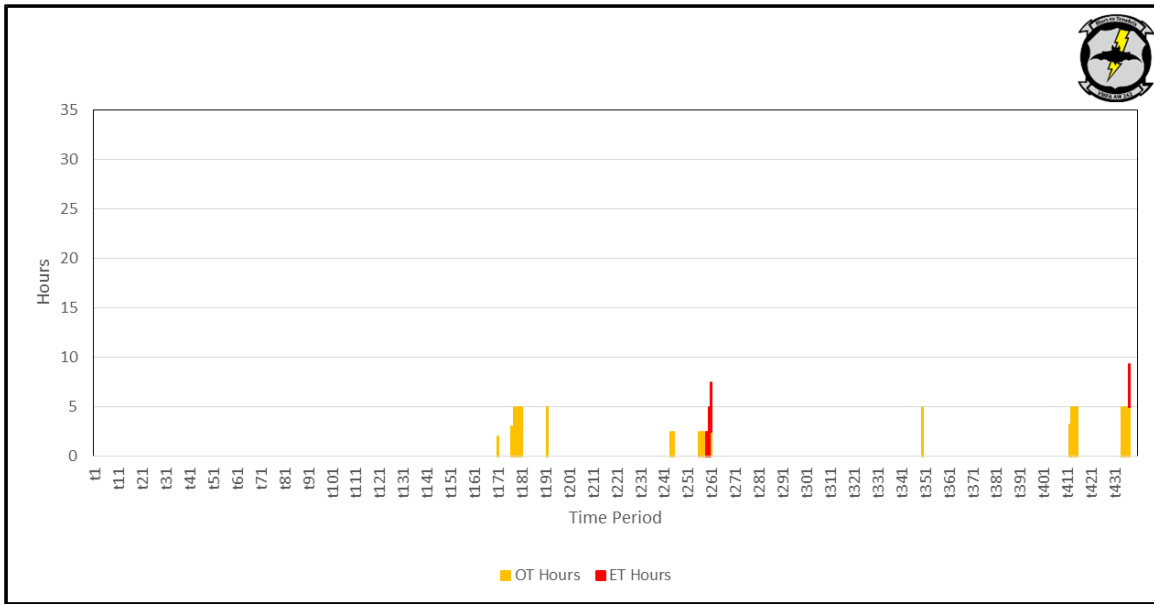


Figure 20. VMFA(AW)-242, WC 13B, CDQAR, Overtime and Extra Time Required, Two Maintenance Days.

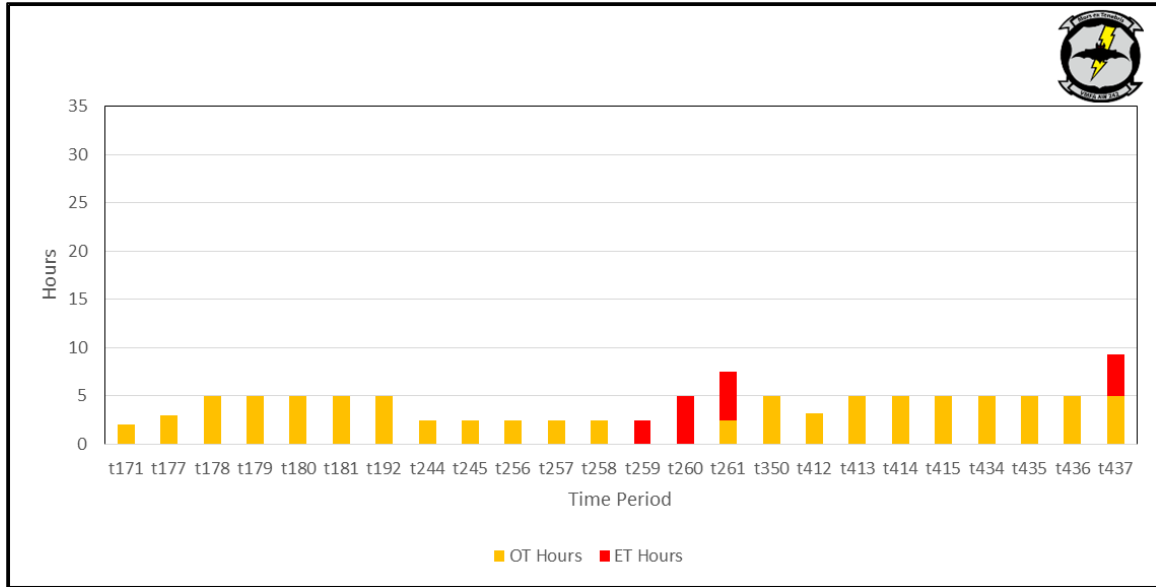


Figure 21. VMFA(AW)-242, WC 13B, CDQAR, Overtime and Extra Time Required, Two Maintenance Days, With Zero-Hour Days Removed.

Table 8. Hours Required For VMFA(AW)-242, WC 13B, All Skill Levels, Overtime and Extra Time.

Type Hours	Number of maintenance days	Mechanic hours	CDI Hours	CDQAR Hours
Overtime	1	235.65	77.3	100.12
Extra Time	1	168.3	139.76	151.32
Overtime	2	122.95	35.04	50
Extra Time	2	53.35	56.1	12.5

4. Hours Utilization

The utilization of hours across WCs is fairly steady and the need for additional man-hours is usually available by working overtime. However, there are WCs, specifically WCs 120 and 13B, which at times do not have sufficient manpower available to complete all work. Figure 22 shows the available and required hours for the CDI level in WC 120 in VMFA(AW)-242 using two maintenance days. There are periods of under-

utilization but there are also many days where the correct amount of hours are available. Blue spikes indicate maintenance days and where a green spike is higher than the blue, for example in the vicinity of *t181*, indicates a day where MVP utilizes extra hours.

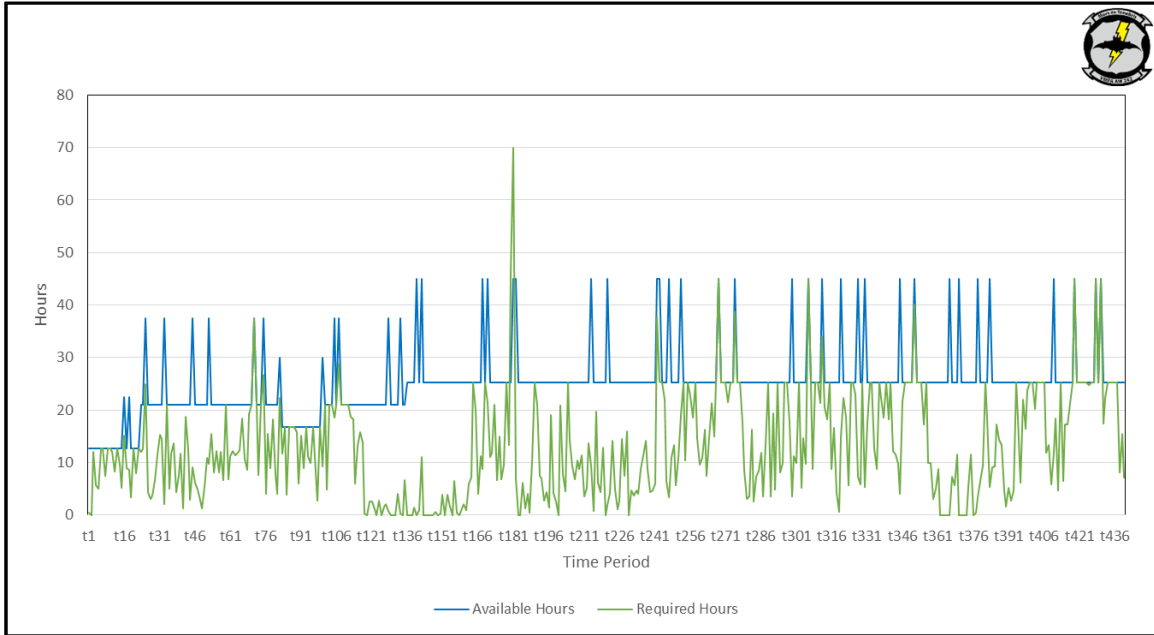


Figure 22. VMFA(AW)-242, WC 120, CDI, Available and Required Hours, Two Maintenance Days.

Figure 23 shows a large gap between the available and required hours for the technician skill level in WC 210. However, one assumption in the MVP is that FAPs have not been removed from the squadron manning level. Normally, if a squadron has to provide a FAP and it is sourced from the maintenance department, it will generally be from WC 210. However, if a reduction is made accounting for five FAPs from the technician skill level in WC 210, it equates to 21 less available hours. At a minimum, there are still 29 hours available which is greater than the maximum requirement for the entire time period.

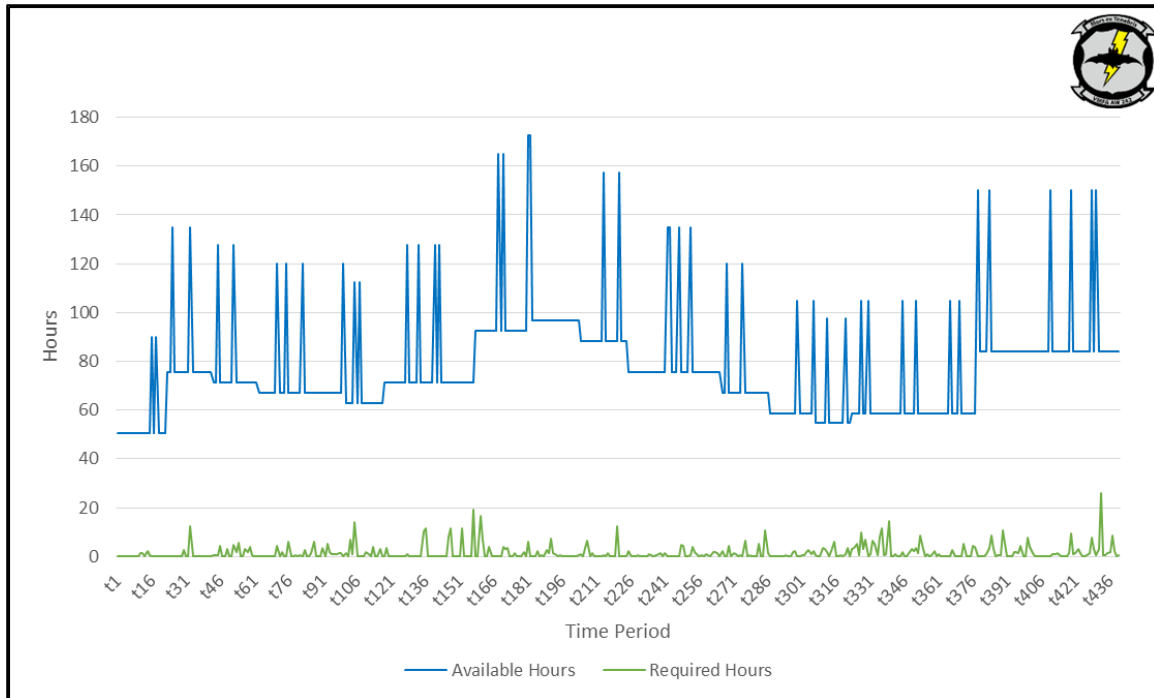


Figure 23. VMFA(AW)-242, WC 210, Technician, Available and Required Hours, Two Maintenance Days.

5. Manpower Excursion

In order to see the effects of altering the manpower in one of the two WCs that requires a large amount of overtime and extra time, we ran an excursion to show the sensitivity of the hour requirements due to a reduction of key personnel. This excursion is run with the number of CDQARs in WC 13B reduced by one in VMFA(AW)-242 for one of the six month periods. Both maintenance day scenarios are run as well as a third which allows for three maintenance days each month.

The time period for this excursion is January 2014 to July 2014, which coincides with *t118-t245* in the MVP. In the original scenario of the MVP, WC 13B has two CDQARs for two of the months and one CDQAR for the other four months. By reducing the number of CDQARs by one, WC 13B has one CDQAR for two months and zero CDQARs for four months.

Overall, there is a large increase in the amount of overtime and extra time for all three skill levels. The amount of extra time the MVP utilizes for the one maintenance day scenario at the CDQAR skill level increases from a baseline total of 98.3 hours to a total of 160.2 hours in the excursion. In the two maintenance day scenario, the extra hour requirement at the CDQAR level increases from a baseline total of 67.6 hours to 181.8 hours in the excursion. The decrease is natural to see from 98.3 to 67.6 hours in the one maintenance day scenario but the increase to 181.8 in the two maintenance day scenario is not. The MVP, while maintaining a similar readiness, chooses a different solution that entails using different maintenance days as well as utilizing a different amount of hours from other WCs. For example, the amount of extra time in the two maintenance day scenario at the CDQAR level in WC 120 also increases, going from a baseline of 20 total hours to 71.9 total hours in the excursion.

We run a third excursion to see if the amount of overtime and extra time can be countered with the addition of a third maintenance day. There is a dramatic decrease in the amount of overtime and extra time requirements but the CDQAR level still requires a total of 105.4 extra hours in order to maintain the required readiness levels.

We run another excursion to see the effects of adding a CDI to the WC 13B baseline manning level in the two maintenance day scenario. The addition of the CDI causes a drastic reduction in the extra time required in all three skill levels. The total extra hours required at the mechanic level reduces from 137.3 to 73 hours, from 185.1 to 147.4 hours at the CDI level, and 181.8 to 79 hours at the CDQAR level. Although the extra hours are still high they are more manageable.

Finally, in order to remain within the historic manning level, we remove three technicians from WC 210 and add a mechanic and a CDI to WC 13B for the same six-month instance as the previous excursions. This change does not cause any requirement for overtime or extra time hours by any WC 210 skill level but it does reduce the extra time hour requirement for all skill levels in WC 13B to zero and also eliminates the WC 120 extra time requirements.

D. ANALYSIS

The MVP adheres to all constraints and abides by all assumptions to attain the daily and monthly RBA requirements. However, it is not able to do so without utilizing the elastic variables for man-hours and extra hours to work on an aircraft. The use of the elastic variables highlight areas of concern.

One of the major assumptions in the MVP is parts are always available. This is not always the case in reality but this is an area where improvement is possible. MALS has a goal of 85% net supply effectiveness, which is effectiveness at filling requirements that are supposed to be in stock, and a goal of 65% gross supply effectiveness, which is effectiveness at filling all requirements (Naval Supply Systems Command 2014). The net supply effectiveness aligns closely with the historic NMCS rate of each squadron during the time period. One of the major insights gained by using this assumption is if parts are available, in most cases there is sufficient manpower available to fix the aircraft.

Extra time required to work on an aircraft may signify reduced readiness. To gain additional hours to work on aircraft, certain improvements can be realized that are not modeled in the MVP, such as being able to work on multiple MAFs on the same aircraft at the same time, but those are likely not enough to cover the amount of extra hours the MVP utilizes. Even allowing MVP to utilize two maintenance days does not eradicate the need for extra time. Additional manpower can only do so much which means the only other option is a reduction in readiness.

The ability to look back and see periods where a lot of overtime and extra time is required to meet the MESM goal of 75% is helpful in planning the future of F/A-18 maintenance. Using the amount of overtime and extra time hours the MVP utilizes in WCs 120 and 13B highlight those WCs as ones squadrons should take great care in manning and using for other tasks besides maintenance. The maintenance days the MVP selects align with days both WCs require overtime and extra time which dictates paying close attention to the workload each WC has. For WC 13B, specifically because the number of Marines is never greater than ten, it is extremely important to manage the manpower very carefully as removing a Marine of any skill level, highlighted by the

reduction of one CDQAR in one of the excursions, has drastic effects on the extra work requirements. Conversely, the addition of manpower to WC 13B countered with a reduction to WC 210 manning, has no negative effects on WC 210 and a large reduction in the amount of extra hours required of WC 13B personnel.

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V. RECOMMENDATIONS AND FURTHER RESEARCH

This thesis provides the ability to plan maintenance based on events that have already occurred. The amount and type of MAFs a squadron has will change over time but the utilization of a two year period for the MVP accounts for variations in deployment schedules as well as hourly maintenance cycles. The workload a squadron has in the future will be similar though it is expected to grow as the F/A-18 continues to fly past the original design specification. It is crucial that the insights gained from this research inspire conversations and plans for action if the USMC desires to continue operating the F/A-18 in the same manner for years to come.

A. RECOMMENDATIONS

1. Manning

Consideration should be given to realigning the manpower level in WC 13B, specifically in the VMFA(AW) squadrons. The manning levels across all five squadrons in WC 13B is generally the same for the two-year period considered in this thesis. However, in the VMFA(AW) squadrons there are twice as many ejection seats to maintain and generally more environmental control system issues on the F/A-18D due to having the same system as the F/A-18A and F/A-18C, but having two of everything to cool from aircrew to displays. Reducing the number of Marines in WC 210 and applying those increases to WC 13B would provide a reduction in the amount of overtime and extra time requirements WC 13B currently has. Increases across all three skill levels in WC 13B are beneficial but the increase in the mechanic and CDI levels are something that can provide benefit relatively quickly as shown in this thesis.

Additionally, though there is an apparent surplus of available hours in WCs when viewed from a MVP perspective, such as the technician level in WC 210, squadrons need to keep all available personnel. There are additional duties not considered by MVP, because the time requirements do not appear on MAFs, that squadrons deal with daily such as being part of a tow crew to move an aircraft in or out of a hangar. Those duties are normally filled by WCs that are not busy.

Squadrons track the levels of qualifications and certifications on a Maintenance Core Competency (MCC) spreadsheet and report it monthly to their higher headquarters as maintenance capability. The levels on the MCC are commensurate with the ability to conduct two shifts of maintenance daily. The two shifts are broken down into a day crew, working from 0700–1630, and a night crew, working from 1630–0200. The MCC report displays squadron numbers in all qualification, certification, and licensing areas and there is a comparison against the requirements, as “developed by senior maintainers throughout the fleet” (CMC 2015) to highlight areas of concern. The onus is on the squadron to make qualifications from within and not rely on inbound Marines to satisfy the requirements for two-shift maintenance.

One of the reasons squadrons cannot rely on inbound Marines to fulfill the requirements of two-shift maintenance is because there are no additional MOS categories that identify a Marine as a CDI or CDQAR. In contrast, aviators receive an additional MOS when they graduate from the Weapons and Tactics Instructor (WTI) course which monitors can use to track qualification levels of squadrons and send WTIs to squadrons or MAGs that require an increase in manning. There are few WTIs in a squadron but they are necessary for mission success. In a similar way, there are few CDQARs in a squadron but they are extremely important for mission success and squadrons need a sufficient allocation.

The assignment of Marines to squadrons is based solely on rank, with the expectation that rank equates to qualification levels, i.e., the expectation is a sergeant is a CDI or a CDQAR. This is not always the case. Given the need for CDIs and CDQARs, as shown in the results of this thesis, consideration should be given to creating two additional MOSs that identify Marines as either a CDI or CDQAR. The creation of these two MOSs will assist monitors in identifying the needs of squadrons and directing qualified personnel to those squadrons based on skill level and not rank.

2. Maintenance Days

The scenarios between one maintenance day and two maintenance days do not reflect a large increase in RBA percentage due to the minimum requirements in the MVP. However, they do highlight ways to overcome the use of overtime and extra time. Extra time is possible for maintainers but the only way to create extra time to work on aircraft is for the aircraft to be NMC for a longer period of time which reduces RBA. Squadrons should strive to schedule two maintenance days each month and give strong consideration to an additional day if a backlog of MAFs is occurring.

3. WCs 120 and 13B

A final insight is the importance WCs 120 and 13B have in terms of maintenance operations. These two WCs drive when the MVP elects to utilize maintenance days. It is therefore essential to keep a close eye on the workload both of these WCs have in order to inform maintenance day decisions. The inundation of WC 120 or 13B with MAFs is a good indication for the CO and AMO to consider creating a maintenance day.

B. RECOMMENDED FUTURE RESEARCH

There are a few areas in which this research can be continued. One of the major assumptions in the MVP is parts availability. Data is available in DECKPLATE that contains maintenance wait times for many areas, but one specific area is waiting for a part to arrive. The MVP could be modified to account for time waiting for a part to arrive before work on a MAF can begin.

This research could also consider the tools available to work on aircraft. For example, whenever there is an issue with the landing gear an aircraft is raised up on jacks. There are not enough sets of jacks to put all aircraft in the air, generally a squadron is fortunate if there are two sets available.

The MVP can also be applied to other type, model, or series of aircraft in the military. Specifically, it would be beneficial for a newer platform, such as the JSF, to have a baseline of manpower usage and as the aircraft ages, run the MVP again and conduct analysis on the amount of extra time the aircraft and WCs require.

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